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Thème

Etude de conception et réalisation d'une fraiseuse 3D à commande numérique (Designing and building a 3D CNC milling machine)

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Abstract:

The purpose of this project is design and making CNC machine, this machine is 3D carving machine; it's controlled numerically with a computer through breakout board named Arduino, which open-source electronic platform that help any person to automate their machines, the machine can move in 3 dimensions moved by 3 stepper motors, the machine is equipped by means of security, to ensure the well function of the machine and the safety of the operator.

Key words: CNC machine, 3D carving, Arduino, design, controlled numerically

Résumé

L'objectif de ce travail est l'étude, la commande et la réalisation d'une CNC machine par Arduino . Il s'agit d'une petite fraiseuse 3D actionné par des motors pas à pas. La machine sera commandée numériquement par ordinateur à l'aide d'interfaçage d'Arduino. La machine se déplace en 3 dimensions au même temps, et à l'aide d'un bouton d'urgence et des fins de cours, la machine et l'operateur sont également en sécurité.

MOTS CLES : fraiseuse, Arduino, CNC, la commande, la réalisation

ملخص

الهدف من هذا المشروع هو دراسة وتصميم و انشاء آلة نحت الخشب ثلاثية الأبعاد، الآلة مصنوعة من الحديد ، تتكون من ثلاثة محاور ، كل محور يحرك بواسطة محرك(خطوة بخطوة) يتحكم بالمحركات ببطاقة تحكم خاصة بArduinoوالذي بدوره يتحكم فيه بواسطة حاسوب .الآلة تستطيع من قطعة خشب مهيأة أن تنحت شكلا ثلاثي الأبعاد.

الآلة مهيأة بعناصر حماية مثل زر الطوارئ وغيره.

كلمات مفتاحية : Arduino،ثلاثي الأبعاد، آلة نحت،تصميم

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Abbreviations

NC	Numerical Control
CNC	Computerized Numerical Control
CAD	Computer Aided Design
CAM	Computer Aided Manufacturing
LSI	Large-Scale Integrated circuits
CAI	Computer-Aided Inspection
CAPP	Computer-Aided Process Planning
CMM	Coordine Measurement Machine
NEMA	National Electrical Manufacturers Association
DIY	Do it Yourself
ID	Internal Diameter
OD	Outside Diameter
KN	Kilo Newton
RPM	Round Per Minute
RPS	Round Per Second

Introduction

The CNC machine, it’s a large world beginning from the CNC machining centers include all kinds of milling (face milling, contour milling, slot milling, etc.), drilling, tapping, reaming, boring, and counter boring, passing by the electrical discharge CNC machine and 3D printer, to CNC router and 3D wood carving. Everything that have been mentioned can’t be covered all in one book, but in this thesis, some basics will be mentioned, so the reader can have general idea about the CNC world.

Arduino is an open-source electronics platform, as we will clarify in this thesis; it’s the tool that made the dream come true, in other words, it summarizes a huge phase in this project, it’s easy and simple to maneuver. It’s the tool that can give us steps ahead toward the development of the science and the technology.

The thesis consists of three chapters, the first is the CNC system in general, historical, the classification and different types, the different organs, and other. In the second chapter, it’s the part programming, how from an imagination of the piece, then primer drafting to a design using CAD software then transferring to CAM software finally, a G-code file, the translation of the desired piece, then comes uploading it into the breakout board Arduino through its soft. Finally for the third chapter, we described the 3D carving machine, the choices, why, how, and by what means.

This project has begun with a thought, and at the end we achieved the goal by making a mini CNC machine, the 3D carving specialty, capable of carving in the wood and also some kind of plastic and aluminum; hoping it’s the first step toward the development not the last.

Chapter 1:

CNC machine

Chapter 1 : CNC machine

1.1 Introduction

We can't talk about the CNC(computer numerical control) system and machine, unless we mention the NC (numerical control) system and machine, which stand for the older and the original Numerical Control which is the technique of giving instructions to a machine in the form of a code that consists of numbers, letters of the alphabet, punctuation marks and certain other symbols. The machine responds to this coded information in a precise and ordered manner to carry out various machining functions, in the purpose of machining parts with complex shape with precision, rapidity and repeatedly.

Both systems perform the same tasks, namely manipulation of data for the purpose of machining a part. In both cases, the internal design of the control system contains the logical instructions that process the data. At this point the similarity ends

In simple words, the CNC system is the technique of using a computer as a means to control a machine that carves useful objects from solid blocks of material, obviously except for the 3D printer.

This chapter consists of basics about the CNC, a historical aspect, general CNC architecture; we will discuss also all kind of classifications and the components of a CNC machine, also mentioning the various types and the uses of a CNC machine.

1.2 History of CNC system and CNC Machine Tools

In marsh 1952 a 3 axis milling machine being the first NC machine tool based on vacuum tubes, the size of NC control unit was bigger than that of the machine tool.

The development of numerical control owes much to the United States air force, which recognized the need to develop more efficient manufacturing methods for modern aircraft. Following World War II, the components used to fabricate jet aircraft became more complex and required more machining. Most of the machining involved milling operations, so the Air Force sponsored a research project at Massachusetts Institute of Technology to develop a prototype NC milling machine. This prototype was produced by retrofitting a conventional tracer mill with numerical control servomechanisms for the three axes of the machine.

In the beginning, the pulse division circuit was made from the computer with ten thousands of vacuum tubes and the machine tool was controlled by activating an oil-pressure motor and controlling relay according to the result of logical processing.

As semi-conductors appeared and applied to NC during the 1960s, electrical motor and power elements during 1970s, and PC components during 1980s, so hardwired NC evolved into soft-wired NC.

Jacquard invented the methods of automatic control of the weaving of fabrics loom machine by using punch cards and this methods was the beginning of the concept of NC.

1.3 Description of CNC machining operation flow

An NC machine which consists of vacuum tubes, transistors, circuits, logic elements such as large-scale integrated circuits (LSI) is called “Hardwired NC”, and performs NC functions through connecting elements by electrical wiring. Instead of elements and circuits, NC functions are implemented based on software in CNC, this change from hardwired NC to CNC was driven by the advance in capacity and availability of microprocessor and memory.

NC machine tools can be classified as “cutting machine” or “non-cutting machine”. A cutting machine is a machine that performs a removal process to make a finished part (ex: milling machine, turning machine,…). Non-cutting machine is the machine that changes the shape of piece of material by applying force and press and press machines are good examples.

The task flow that is needed for producing a part is:

- Offline tasks: CAD, CAPP, CAM.
- Online tasks: NC machining, monitoring and On-machine measurement.
- Post-line tasks: Computer-Aided Inspection (CAI).

Offline tasks are the tasks needed to generate a part program for the control of the machine, they consist of CAD step (the geometric modeling stage); CAPP step (which machine? tool, cutting conditions…); CAM step, uses the information from CAD and CAPP steps to generate tool path considering minimizing of machining time and tool change, considering also the machine performance.

Online tasks is the stage which the NC machine read and interprets part program from memory and generating instructions for position and velocity control and on these instructions stepper motors or servo motors are controlled; by the movements of the axes and the spindle the work piece is machined.

Post-line tasks: is the inspection stage using a CMM (Coordine Measurement Machine) to compare the result with the geometry model, it may include re-machining and grinding.

Computer Numerical Control (CNC) is based on the concepts of NC but uses a dedicated computer within the machine control unit to store the program. CNC is largely the result of technological progress in microelectronics (the miniaturization of electronic components and circuitry).

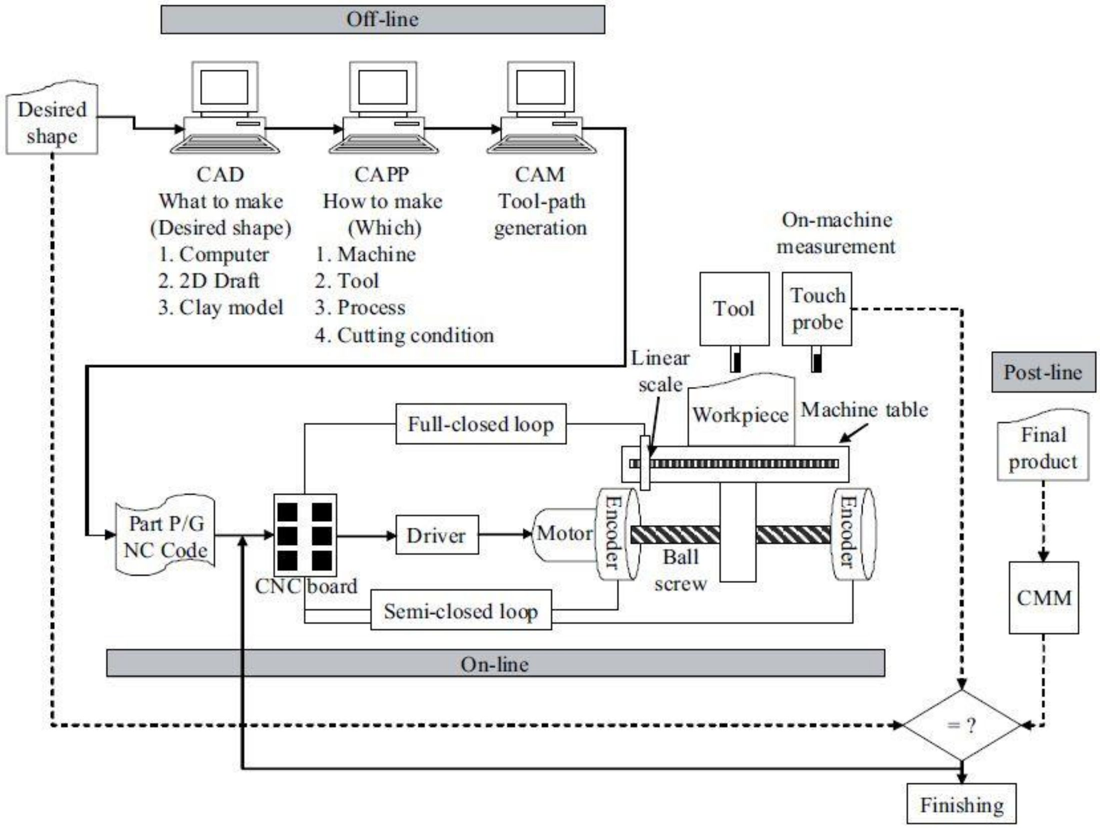


Figure 1-1: The architecture of CNC machine tools and machining operation flow

1.4 Components of CNC machine

This section consists almost of all the necessary equipment and hardware used to compose a CNC machine. Because the field of CNC is large, so these mentioned components are destined for small or average industrial CNC.

The architecture of CNC machine tools in general is shown in the figure 1-1

1.4.1 Physical Architecture

In this section, everything that is related to the CNC building will be stated according to small and medium CNC size.

1.4.1.1 RouterHead

The use of a standard woodworking type of router head is quite common on hobby and entry-level CNC Routers. The reason why this type of motor is used so often is because of its low cost. The type of motor used is referred to as an induction motor. Note that if you spend much time around this type of motor while it is running, you will want to wear some type of hearing protection, as they are quite loud.

Figure 1-3: Spindle head

Figure 1-2: Router head

1.4.1

Spindle heads are physically analogous to a router head, but they work in conjunction with a spindle drive (known as a variable-frequency drive [VFD]) and are frequency controlled to vary the revolutions per minute. Spindle heads are designed and intended for heavier-duty CNC use and typically come with ceramic-style bearings, which are resilient to the higher loads being placed on them. They also yield very low amounts of shaft run out.

1.4.1.3 Hold-Down Methods

When performing rotary cutting, the rotating moving bit exerts forces on the material being worked on. To counteract these forces, there are several ways to hold the work material solidly in place. Although any of the below-mentioned hold-down methods will work, each method may not be the optimum solution in each case. It is the user's responsibility to choose and use a hold-down technique that is adequate and safe for each cutting job being performed. Attempting to hold material in place with your hands during a cutting operation is never an option. We can count 4 types of hold-down methods:

- Vacuum
- T Track Grid Work
- Double-Sided Tape
- Fat Mat

Figure 1-5:Example of Vacuum hold-down method

Figure 1-4:T Track Grid Work and Vacuum hold-down method

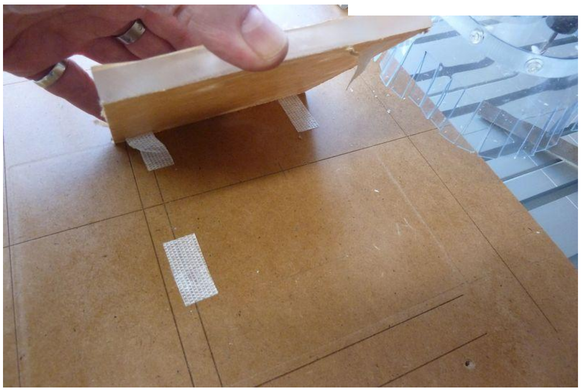


Figure 1-6 : example of Double-Sided Tape hold-down method

1.4.1.4 Limit and Homing Switches

Switches are not considered an application, but rather a set of controller peripheral devices. The types of switches generally used are micro-switches, which are mounted such as to sense the physical extremes of travel for each axis and in each direction of travel. When using the switches in a capacity of limits, they are intended as safety devices to immediately stop travel of the axis prior to a crash or the gantry running off the end of the table. When looking at the switches with regard to homing, the locations for where each switch trips is a known location.

In the event your system experiences a loss of steps condition or the power to your shop goes out, the homing routine will put your machine back into a known working set of coordinates.

Figure 1-7 : Micro-switch used for limits and homing.

1.4.1.5 Tooling

Within the machining and CNC world, the term tooling simply means the cutter you intend to use. There are a great many categories of tooling that can be used and are somewhat specific to the type of machine and material you will be working with. There are so many different types of tooling that are associated with each facet of CNC machining that it would take a separate chapters to cover them all.

1.4.1.6 Guide system

In this section we will explore the various methods in which the individual axes of the machine derive their motion. All of the systems we will explore are considered to be "linear" guides, as that is the type of motion they yield. Regardless of which type, they all must provide the following:

- Rectilinear (i.e., back and forth) motion along the intended axis
- Smooth straight movement with minimal friction
- Rigid orientation, fixed at 90 degrees (i.e., orthogonal) to the other axes
- Rigid mounting with minimal play between the carriage and guide Round Rail.

Round rail

This system makes use of a round rail or rod that provides the linear guide path for one or more bearing blocks to traverse along its length (see Figure1-6). The diameters of the rail are available anywhere from 1/8 up to 4-in and are found in lengths up to 20 ft. This type of rail is typically not the same stock as what you would find at your local steel supplier, as it is precision ground to exacting tolerances.

Figure 1-8 : example of round rail

Profile Rail

This guide system (see Figure1-7) derives its name from the shape of the rails' cross section. It has profiled pathways to accept the steel balls contained in the carriage. This is a very popular choice among many users, particularly with designs requiring high-load requirements or precise guide ways. As we will discuss, this system has a great many number of advantages, but it is however, one of the most expensive systems to purchase and can be difficult to install.

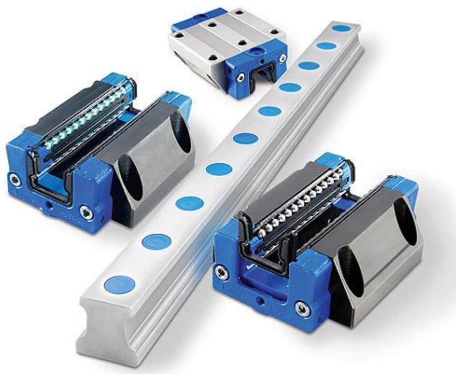


Figure 1-9 : Example of profile rails.

V-Style Roller

This style of linear guide system is a popular choice for use on CNC router and plasma table designs. It is simple in design, implementation, and use and requires little to no maintenance with a long life expectancy. This guide type uses steel wheels with a profiled "V" around the perimeter that ride against a hardened steel track, which has a complementary profile (in reverse) to match. These wheels use a dual row of ball bearings giving them high radial load-carrying ability in a relatively small size. The reasons behind the popularity of this system are many:

• All parts are available as components - you can easily attach the rail to your own mounting substrate directly on the machine's framework.

• The carriages and railing are available in assembled units in various lengths and sizes.

• Lowest cost of the guide system choices.

• Operates in any environment.

• Low profile.

• Low maintenance.

• Easiest to install.

Figure 1-10 : example of V-roller

Hybrid Roller Guides

Working on the same principles as the V-roller technology, some manufacturers use half-moon profile rollers in conjunction with hardened steel rods embedded into a base substrate. The hybrid roller system shown in Figure1-9 is made by Pacific Bearing.

Figure 1-11 :example of hybrid Roller

1.4.1.7 Transmission Systems

There are many ways in which power from a motor can be applied to machinery for various types of movement. Methods such as hydraulic, pneumatic, belt, chain, cable, rack and pinion, and screws are but a few that can be used. However, when dealing with CNC, we are particularly interested in obtaining resolution and accuracy, as well as bidirectional travel. In this section, we will discuss the two most common methods in which the rotary power from the motor is translated into linear motion. The function of the transmission system is to translate the rotational power of the motor into linear movement. To meet these criteria, almost all CNC equipment will use either rack and pinion or some type of screw and nut mechanism to produce rectilinear movement. In addition, there can be hybrid systems in which both the guide and transmission are incorporated into one unit.

Screw and Nut

There are several synergies in comparing a lead screw to a ball screw. Among them are how they are mounted (end fixity), nut mounting, and driving method of the screw and its lead (pronounced lead) values (axial movement per shaft rotation)—all of which we will discuss next.

End Fixity

Regardless of the screw style being used, there are four basic methods in which a lead or ball screw can be mounted for use. These are:

- Both ends fixed
- One end fixed with the other end supported
- Both ends supported
- One end fixed with other end free

Lead Screw and Nut

Trapezoidal thread forms are screw thread profiles with trapezoidal outlines. They are the most common forms used for lead screws (power screws). They offer high strength and ease of manufacture. They are typically found where large loads are required, as in a vise or the lead screw of a lathe. Standardized variations include multiple-start threads, left-hand threads, and self-centering threads (which are less likely to bind under lateral forces).

Lead screws have a thread form known as Acme. These are commonly referred to as Acme screws. This shape is easier to machine (faster cutting, longer tool life) than is a square thread. The tooth shape also has a wider base which means it is stronger (thus, the screw can carry a greater load) than a similarly sized square thread.

Backlash is the amount of play or movement of the nut

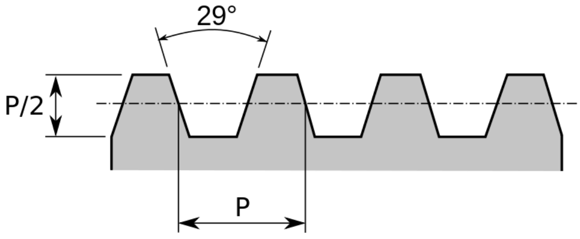


Figure 1-12 : Basic Acme thread profile

Figure 1-13 :Lead screw assembly with one-piece nut.

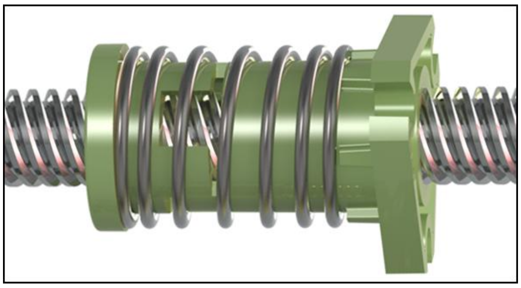


Figure 1-14: Lead screw assembly with two-pieces nut (anti-backlash)

Ball Screws

There are several advantages that ball screws have over lead screws. Among these are efficiency, precision, higher-load capacity, longer life expectancy, higher operating speeds, and ability to back-drive via a rotating nut. Ball screws are the higher cost and higher performing of the two choices of screws. Unlike their counterpart, ball screws all have a very high percentage ability of transferring almost all of the rotary power into linear motion. In fact, ball screws typically have efficiency ratios at 90 percent or greater, whereas lead screws rarely achieve even 75, with 50 percent being more common. This is primarily achieved from the method in which the ball nut interfaces with the screw ball bearings. Rather than having a lot of material from a lead screw nut friction sliding against the screw, the ball bearings rotate or spin within the tooth form of the ball screw, greatly minimizing the force required to rotate the screw. These ball bearings are all fit within a channel (or channels) that reside in the ball nut. Hence, not all of the bearings are in contact with the thread form at any given time, but recirculate throughout its circuit.

Figure 1-15: example of ball screw

Rack and Pinion

The use of a rack and pinion is generally the most popular method of mechanical translation methods when longer distances are required, as is the case in large-format routers and plasma machines. This is primarily because of cost issues, as rack and pinion is undoubtedly more cost effective than using either lead or ball screws. There are two methods in which to use the rack and pinion combination:

- The most common method is to affix the rack to a stationary portion of the machine frame and drive the pinion, which is fixed to the moving part of the machine.
- The second involves fixing the pinion gear in one location and having it drive the gear rack. In an example of the latter implementation the bed of the machine moves back and forth, instead of having a movable gantry

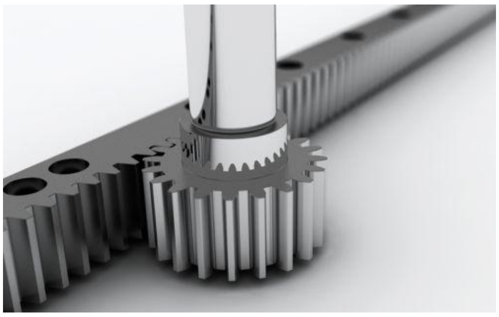


Figure 1-16: Section of rack with a pinion gears.

1.4.1.8 Motors

Stepper Motors

Undoubtedly the largest portion of hobby and midrange shop-based CNC machines available on the market today use stepper motors (Figure1-15). This style of motor has a rather large number of magnetic *poles* contained within the stator winding. Having a large amount of poles enables the rotor (the rotating part) to achieve very small increments of rotational movement. This ability is intrinsic to all stepper-based motors where each of the 200 divisions of rotation is 1.8 degrees. This is derived from 360 degrees of one rotation divided into 200 segments. These are the most common motors and, when coupled with a 10-step multiplier drive, the result is 2000 steps per revolution of the motor's output shaft. As a result of this intrinsic granularity, stepper motors do not *require* the use of an encoder for their operation and are considered *open loop* in this situation. Stepper motors come available in many different physical sizes and adhere to an industry specification for standards known as National Electrical Manufacturers Association (NEMA). The specific sizes that are typically used on CNC devices, such as engraving machines, routers, and mills are NEMA 17, NEMA 23, NEMA 34, and NEMA 42. It is important to note that the smaller the number, the smaller the frame size is for mounting the motor. For example, the overall footprint for a NEMA 23 motor is 2.3-in square and 3.4-in square for a NEMA 34 motor. Stepper motors are available as single-, double-, or triple-stack, which relates to the amount of holding torque the motor is capable of

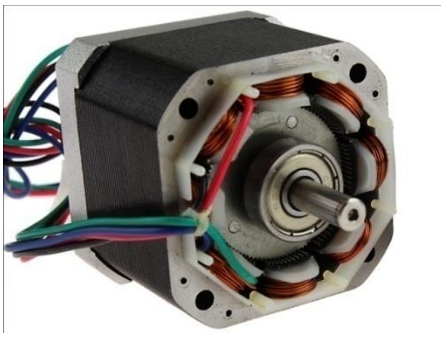


Figure 1-17:opened stepper motor

Servo Motors

Servo motors and stepper motors can physically resemble each other when viewed from the outside. It's the configuration of the rotor and stator inside that makes the difference between the two. Servo motors in comparison to stepper motors have considerably fewer number of magnetic poles in their windings. As a result, servo motors require the use of an encoder / resolver feedback device to be able to constantly make the required changes in order to achieve positional accuracy. This is what is referred to as "closed loop." In fact, without the use of positional feedback or closed-loop functionality, a servo motor would be useless for any type of CNC application. Most servo motors have a device known as a Hall-effect sensor that senses changes in the electromagnetic field of the motor during operation and is used to provide the feedback information to the drive/amplifier as to its exact physical location.

Figure 1-18: example of a servo motor

1.4.2 CNC Controller

The physical controller is comprised of various components necessary in the conversion of software commands that result in electrical signaling to drive the motor. This chapter discusses the enclosure and various components that are used, as well as devices typically used in conjunction with the controller.

Enclosure

The goal of the enclosure is to provide a safe and dust-free environment for the electronics. It also provides easy access to wiring of the various components. Properly sized access and mounting holes are usually made in the face of the housing for an ON/OFF switch, as well as an emergency power off (EPO) switch. Typically the back of the box provides wiring access for the db-25 port and motor wiring connections. Other connections can include those for limit and homing switch input, Z axis zeroing touch-off, remotely controlled EPO switches, etc. Shown in Fig. 5-2 is an enclosure with a breakout board, five drives, spindle speed controller, and transformer ready for wiring.

Breakout Board

There are numerous types of breakout board, depending on the task needed to be done by the CNC, it depends also on power of the task.

A. Standard breakout board

As the name implies, this type of printed circuit board performs a breakout of the signals present on each of the pins on the db-25 connection coming from the computer's parallel port. These boards are also commonly referred to as a BOB, which is short for breakout board. One of the primary functions of any breakout board is to provide some form of electrical isolation between the computer and the controller. This is critical as any anomalies in wiring or spikes in voltage will isolate the damaging electricity from migrating back to the physical port on the computer. These types of boards also provide convenient connections for the user to interface with the components. Some breakout boards have more features than others, but all provide basic connectivity required for step and direction signaling for each axis and phased output signaling for each motor.

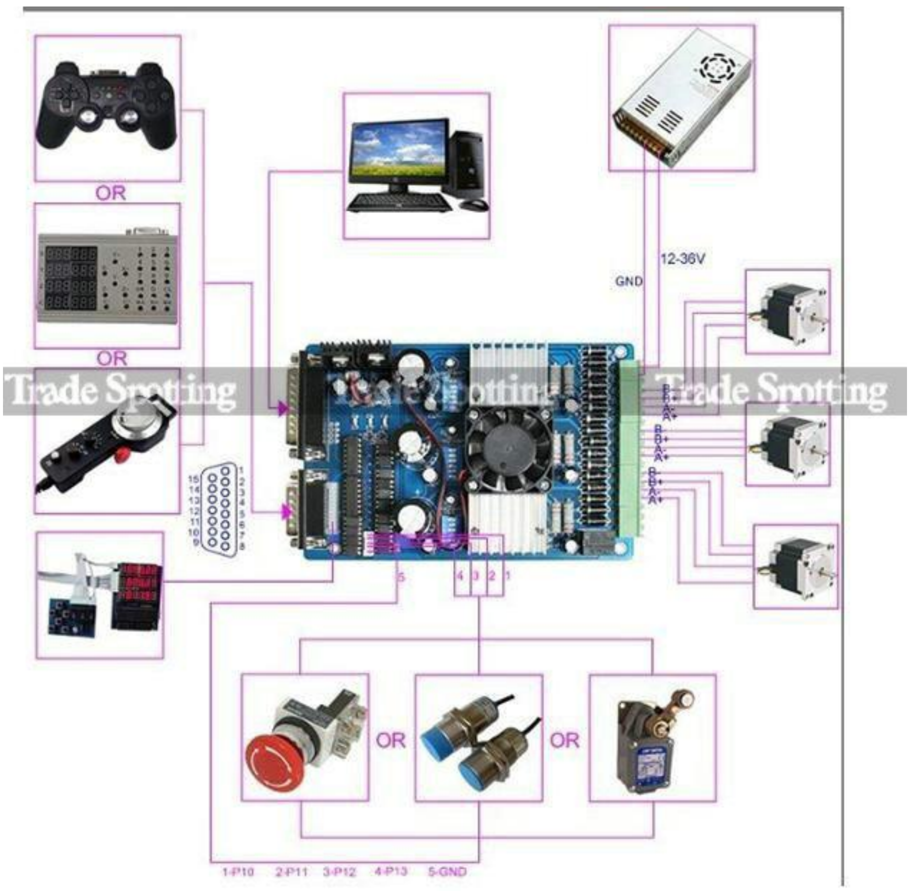


Figure 1-19: CNC breakout board and its wiring

1.4.3 Arduino

The Arduino is an open hardware microcontroller platform. It consists of a printed circuit board with a microcontroller and all the supporting hardware necessary to use the microcontroller mounted on it. All of the designs for the PCB (printed circuit board) layouts are freely available. A simple IDE (integrated development environment) has been created, and many code libraries have been written (Arduino website). This has simplified working with microcontrollers, and has opened up the world of microcontrollers to people who would otherwise have been deterred by the complexity of working with them. The Arduino is an excellent platform for simple microcontroller tasks, as it is affordable and easy to work with. The Arduino comes in many variations, and it is either based on an 8-bit Atmel AVR microcontroller or a 32-bit Atmel ARM. An Arduino will be used to control the CNC milling machine that will be built. As the Arduino will be used to run the G-code interpreter Grbl, it will need to be based on the 8-bit Atmel ATMEGA328 microcontroller.

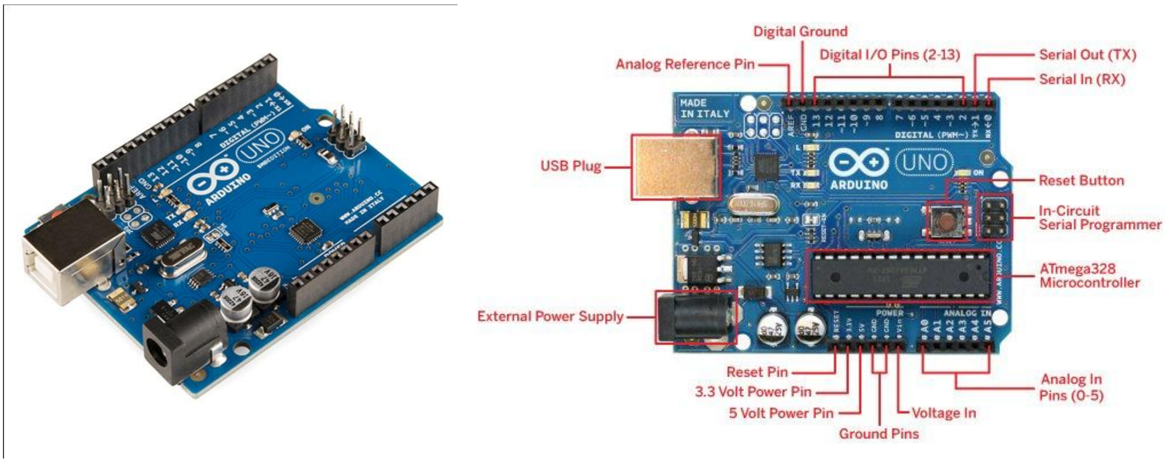


Figure 1-20:Arduino Uno, pins description

Power Supply

All controllers will have some form of incorporated power supply (standalone or integral to the drives themselves) that provide the designed voltage and amperage necessary to drive the motors.

Figure 1-21:standard power supply

Spindle-Speed Controller

Most CNC applications that require rotary cutting or engraving have some type of a frequency-driven spindle. The use of a spindle-speed controller transfers the spindle control from the drives' panel to the software. The same functionality of the spindle (i.e., ON/OFF, forward/backward, and rpm) is then controlled via the computer with software commands. These commands can either be manually issued or from G code in an automated manner.

Figure 1-22: Spindle-Speed Controller

Pendant

A pendant is a relatively small hand-held device that the user plugs into either a USB or serial port connection, allowing remote control of the machine (obviously within the limits of the length of the cord). Keys on the pendant are able to be programmed or assigned various functions that are normally executed via the keyboard. Customary remote functions typically are: move, rapid, z touch off routine, pause, stop, file start, etc.

Figure 1-23: example of pendent

1.4.3.1 Coolants and lubricants

When the tool contacts the material for an extended period of time, a great amount of heat is generated. The cutting edge gets overheated, becomes dull and may break. To prevent these possibilities, a suitable coolant must be used.

Water soluble oil is the most common coolant. A properly mixed coolant dissipates heat from the cutting edge and it also acts as lubricant. The main purpose of lubrication is to reduce friction and make the metal removal easier.

The CNC programmer decides when to program the coolant and when not. Ceramic cutting tools are normally programmed dry, without a coolant. Some cast irons do not require flood coolant, but air blast or oil mist may be allowed.

1.5 Classification of CNC machine

In present era, variety, complexity of geometry, tolerances, skill of personnel and availability of funds by considering all factors, the NC machines are designed according to meet different requirements within the cost constraints. These machines are broadly classified as the following:

1.5.1 Based on feedback control

In the NC machines, to control the position of a machine slide, a group of electro-mechanical, pneumatic or hydraulic components are used which are collectively known as

Servo Mechanism. The output from the data handling equipment is passed through separate channels to servo system, which in turn drives the machine slides. This servo system, based on feedback control, can be approached in as following:

1.5.1.1 Open Loop System

In an open loop system the machine slides are displaced according to the information loaded from the part program into the control system. Hence there is no measurement of slide position and no feedback signals for comparison with the input signal. The correct movement of slide entirely depends upon the ability of the drive systems to move the slide through the required exact distance. The most common method of driving the lead screw is by a stepper motor. The stepper motors are the simplest way for converting detail electrical signals into proportional movement. As there is no check on the slide position, the system accuracy depends upon the motors ability to step through the exact number of steps provided at the input.

1.5.1.2 Closed Loop System

A closed loop system is sends back a signal to the control unit from a measuring device called as transducer. The transducer is attached to the slide ways. The signal indicates the actual movement and position of the slides. The control unit continues to adjust the position of the slide until it arrives its destination, this system has feedback. Although more costly and complex than open loop system, these system gives more accurate positioning. For this type of system, servomotors are used.

1.5.2 Classification based on driving ystem

The driving system is an important component of a CNC machine as the accuracy and repeatability depend very much on the characteristics and performance of the driving system. The requirement is that the driving system has to response accurately according to the programmed instructions. This system usually uses electric motors although hydraulic motors are sometimes used for large machine tools. The motor is coupled either directly or through a gear box to the machine lead screw to moves the machine slide or the spindle. Three types of electrical motors are commonly used.

- DC Servo Motor and Brushless DC Servomotors
- AC Servo Motors
- Stepper Motors

1.6 Types of CNC machine tools

As stated, CNC has touched almost every facet of manufacturing. Many machining processes have been improved and enhanced through the use of CNC. Let's look at some of the specific fields and place the emphasis on the manufacturing processes enhanced by CNC machine usage.

1.6.1 In the metal removal industry

Machining processes that have traditionally been done on conventional machine tools that are possible (and in some cases improved) with CNC machining centers include all kinds of milling (face milling, contour milling, slot milling, etc.), drilling, tapping, reaming, boring, and counter boring.

In similar fashion, all kinds of turning operations like facing, boring, turning, grooving, knurling, and threading are done on CNC turning centers.

There are all kinds of special "off-shoots" of these two machine types including CNC milling machines, CNC drill and tap centers, and CNC lathes.

Grinding operations of all kinds like outside diameter (OD) grinding and internal diameter (ID) grinding are also being done on CNC grinders. CNC has even opened up a new technology when it comes to grinding. Contour grinding (grinding a contour in a similar fashion to turning), which was previously infeasible due to technology constraints is now possible (almost commonplace) with CNC grinders.

Figure 1-24: (a) example of CNC lathe (b) example of CNC Grinder

Figure 1-25: CNC Tapper in function

1.6.2 In the metal fabrication industry

In manufacturing terms, *fabrication* commonly refers to operations that are performed on relatively thin plates. Think of a metal filing cabinet. All of the primary components are made of steel sheets. These sheets are sheared to size, holes are punched in appropriate places, and the sheets are bent (formed) to their final shapes. Again, operations commonly described as fabrication operations include shearing, flame or plasma cutting, punching, laser cutting, forming, and welding. Truly, CNC is heavily involved in almost every facet of fabrication.

CNC back gages are commonly used with shearing machines to control the length of the plate being sheared. CNC lasers and CNC plasma cutters are also used to bring plates to their final shapes. CNC turret punch presses can hold a variety of punch-and-die combinations and punch holes in all shapes and sizes through plates. CNC press brakes are used to bend the plates into their final shapes.

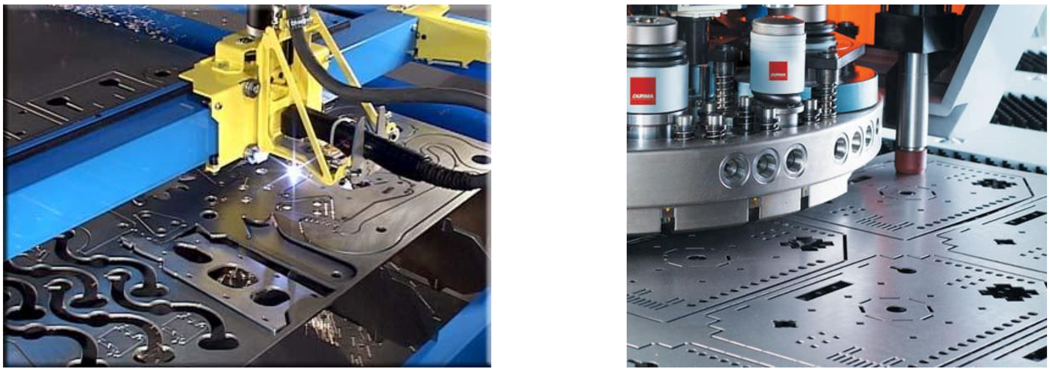


Figure 1-26: (a) CNC Plasma Cutter in duty (b) example of CNC punch

1.6.3 In the electrical discharge machining industry

Electrical discharge machining (EDM) is the process of removing metal through the use of electrical sparks which burn away the metal. CNC EDM comes in two forms, vertical EDM and Wire EDM. Vertical EDM requires the use of an electrode (commonly machined on a

CNC machining center) that is of the shape of the cavity to be machined into the work piece. Picture the shape of a plastic bottle that must be machined into a mold. Wire EDM is commonly used to make punch and die combinations for dies sets used in the fabrication industry. EDM is one of the lesser known CNC operations because it is so closely related to making toolingused with other manufacturing processes.

Figure 1-27: (a) Vertical EDM, (b) CNC EDM in service

1.6.4 In the woodworking industry

As in the metal removal industry, CNC machines are heavily used in woodworking shops. Operations include routing (similar to milling) and drilling. Many woodworking machining centers are available that can hold several tools and perform several operations on the work piece being machined.

Figure 1-28:(a) CNC router,(b) CNC Wood machine center

1.6.5 Other types of CNC machines

Many forms of lettering and engraving systems use CNC technology. Water jet machining uses a high pressure water jet stream to cut through plates of material. CNC is even used in the manufacturing of many electrical components. For example, there are CNC coil winders, and CNC terminal location and soldering machines.

1.7 Conclusion

This chapter speaks about the CNC machine from the beginning; the standard components of it and the classifications and the types of the CNC machine.

All what is mentioned before was just a little briefing of the CNC world, it could be a window for a starter in CNC matter, we could speak about the end mill (type of bits), the guarding system (safety and protection procedures),

Chapter 02:

Programming part

Chapter 2 : Programming part

2.1 Introduction

The development of any CNC program begins with a very carefully planned process. Such a process starts with the engineering drawing (technical print) of the required part released for production. Before the part is machined, several steps have to be considered and carefully evaluated. The more effort is put into the planning stage of the program, the better results may be expected at the end.

The steps required in program planning are decided by the nature of the work. There is no useful formula for all the jobs, but some basic steps should be considered:

- Initial information
- Machine tools features
- Part complexity
- Manual programming
- Computerized programming

2.2 Initial information

Most drawing defines only the shape and size of the completed part and normally does not specify data about the initial blank material. For programming, a good knowledge of the material is an essential start, mainly in terms of its size, type, shape, condition, hardness, etc. the drawing and material data are the primary information about the part. At this point, CNC program can be planned. The objective of such a plan is to use the initial information and establish the most sufficient method of machining, with all related consideration, mainly part accuracy, productivity, safety and convenience.

2.3 Machine tools features

No amount of initial information is useful if the CNC machine is not suitable for the job. During program planning, programmer concentrates on a particular machine tool, using a particular CNC system.

The most important consideration in program planning is the type and the size of the CNC machine, particularly its work space. Other feature, equally important, are the machine power rating, spindle speed and feed rate range, number of tool stations, tool changing system, available accessories, etc.

The control system is the heart of a CNC machine. Being familiar with all the standard and optional features available on all controls is a must. This knowledge allows the use of a variety of advanced programming methods, such as the machining cycles, subprograms, macros and other timesaving features of a modern CNC system.

2.4 Part complexity

At the time, the drawing, material and the available CNC equipment are evaluated; the complexity of the programming task becomes much clearer. How difficult is to program the part manually? What are the capabilities of the machines? What are the costs? Many questions have to be answered before starting the program.

Difficult or complex jobs will benefit from a computerized programming system. Technologies such as Computer Aided Design (CAD) and Computer Aided Manufacturing (CAM) have been strong part of the manufacturing process for many years.

2.5 Manual programming

Manual programming (without computer) has been the most common method of preparing a part program for many years. In manual programming all calculation are done by hand, with the aid of pocket calculator, and the programmed data can be transferred to the CNC machine via cable; short program can also be entered manually, by keyboard entry, directly at the machine.

2.5.1 Disadvantages

There are some disadvantages associated with manual programming. Perhaps the most common is the length of time required to actually develop a fully functioning CNC program. The manual calculations, verifications and other related activities in manual programming are very time consuming. Other disadvantages are the large percentage of errors, a lack of tool path verification, the difficulty in making changes to a program, and many other.

2.5.2 Advantages

On the positive side, manual part programming does have quite a few unmatched qualities. Manual programming is so intense that it requires the total involvement of the CNC programmer and yet offers virtually unlimited freedom in the development of the program structure. Programming manually does have some disadvantages, but it teaches a tight discipline and organization in program development. It forces the programmer to understand programming techniques to the last detail. In fact many useful skills learned in manual programming are directly applied to CAD/CAM programming.

2.6 **Computerized programming**

The need of improved efficiency and accuracy in CNC programming has been the major reason for development of a variety of methods that use a computer to prepare part programs. Computer assisted CNC programming has been around for many years. Since the late 1970’s, CAD/CAM has played a significant role by adding the visual aspect to the programming process. The whole subject of CAD/CAM covers much than just design, drafting and programming. It is also known as CIM –Computer Integrated Manufacturing.

2.7 **CAD software**

CAD, or computer-aided design and drafting (CADD), is the use of computer technology for design and design documentation. CAD software replaces manual drafting with an automated process.

These programs can help you explore design ideas, visualize concepts through photorealistic renderings, and simulate how a design will perform in the real world.

CAD software is used to increase the productivity of the designer, improve the quality of design, improve communications through documentation, and to create a database for manufacturing.

CAD is an important industrial art extensively used in many applications, including automotive, shipbuilding, and aerospace industries, industrial and architectural design, prosthetics, and many more. CAD is also widely used to produce computer animation for special effects in movies, advertising and technical manuals, often called DCC digital content creation.

AutoCAD software was the first CAD program, than others come after as SolidWorks, and others.

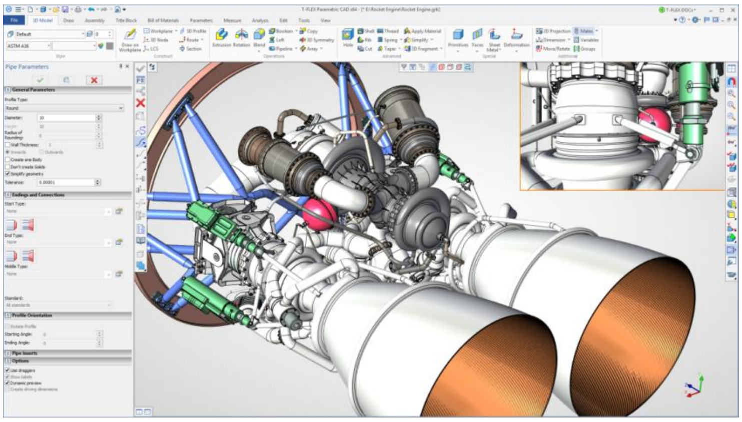


Figure 2-1: example of design using CAD software 1

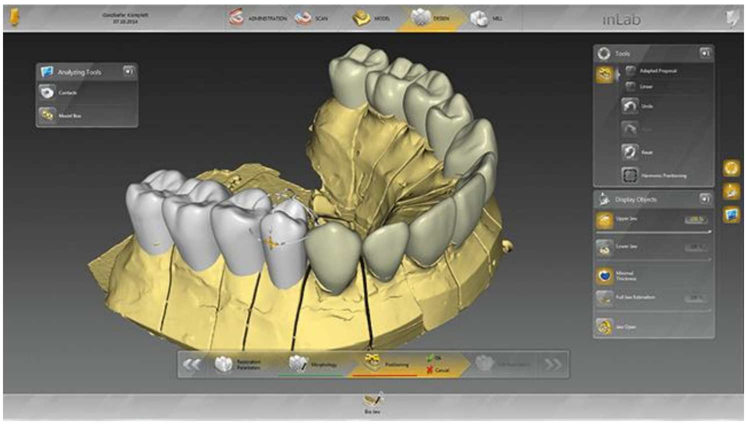


Figure 2-2: example of design using CAD software 2

2.8 CAM software

Computer-aided manufacturing (CAM) commonly refers to the use of numerical control (NC) computer software applications to create detailed instructions (G-code) that drive computer numerical control (CNC) machine tools for manufacturing parts. Manufacturers in a variety of industries depend on the capabilities of CAM to produce high-quality parts.

A broader definition of CAM can include the use of computer applications to define a manufacturing plan for tooling design, computer-aided design (CAD) model preparation, NC programming, coordinate measuring machine (CMM) inspection programming, machine tool simulation, or post-processing. The plan is then executed in a production environment, such as direct numerical control (DNC), tool management, CNC machining, or CMM execution.

2.8.1 Benefits of CAM

The benefits of CAM include a properly defined manufacturing plan that delivers expected results in production.

- CAM systems can maximize utilization of a full range of production equipment, including high speed, 5-axis, multi-function and turning machines, electrical discharge machining (EDM) and CMM inspection equipment.
- CAM systems can aid in creating, verifying, and optimizing NC programs for optimum machining productivity, as well as automate the creation of shop documentation.
- Advanced CAM systems with product lifecycle management (PLM) integration can provide manufacturing planning and production personnel with data and process management to ensure use of correct data and standard resources.
- CAM and PLM systems can be integrated with DNC systems for delivery and management of files to CNC machines on the shop floor.
- Offsetting: Compensating for Kerf Kerf is the gap made by cutting with a saw blade–or an end mill. As the cutter follows the tool path through the material, it leaves a path (as wide as the bit) where there is no material left. To compensate for kerf and cut dimensionally accurate 2Dparts, the end mill needs to be offset from the vector by half the diameter of the tool.

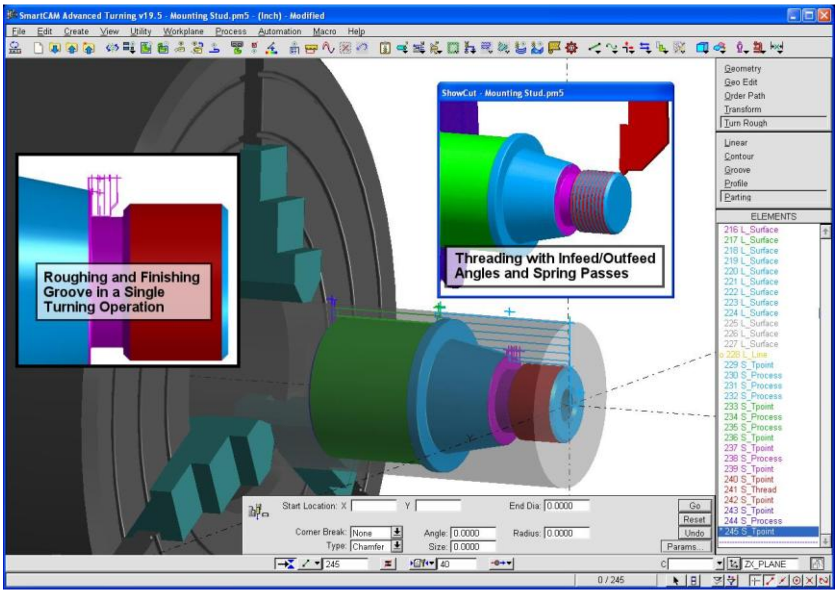


Figure 2-3: screen shot of CAM software (Smart CAM soft)

2.8.2 Integration

the keyword in the acronym CIM is integration. It means putting all the elements of manufacturing together and work with them as a single unit and more efficiently.

The main idea behind a successful integration is to avoid duplication .one of the most important rules of using a CAD/CAM computer software is: “ never do anything twice”

When a drawing is made in CAD software, then done again in CAM software, there is duplication. Duplication breeds errors. In order to avoid duplication, most of the CAD systems incorporate a transfer method of the design to the selected CAM system to be used for CNC programming.

Typical transfers are achieved through special DFX or IGES files. The DFX stands for Data Exchange Files or Drawing Exchange files, and the IGES abbreviation is a short form of Initial Graphics Exchange Specification files.

Once the geometry is transferred from the CAD system to the CAM system, only the tool path related process is needed.

Passing through CAM software can be avoided by including special library called "CAM works" into SolidWorks CAD software.

Using either one of these methods or by another means, a G-code file or M-file is generated ready to be downloaded directly to the CNC machine.

2.9 Part setup

Some machine tools require that the cutting tool and work piece shall be placed at certain positions and also be moved relative to each other. Based on the relative motion, the NC machines can be classified as:

2.9.1 Point to Point Motion

Some machine tools for example drilling, boring and tapping machines etc, require the cutter and the work piece to be placed at a certain fixed relative positions at which they must remain while the cutter does its work. These machines are known as point-to-point machines. The control equipment for use with them is known as point-to-point control equipment. Feed rates need not to be programmed. In these machine tools, each axis is driven separately. In a point-to-point control system, the dimensional information that must be given to the machine tool will be a series of required position of the two slides. Servo systems can be used to move the slides and no attempt is made to move the slide until the cutter has been retracted back.

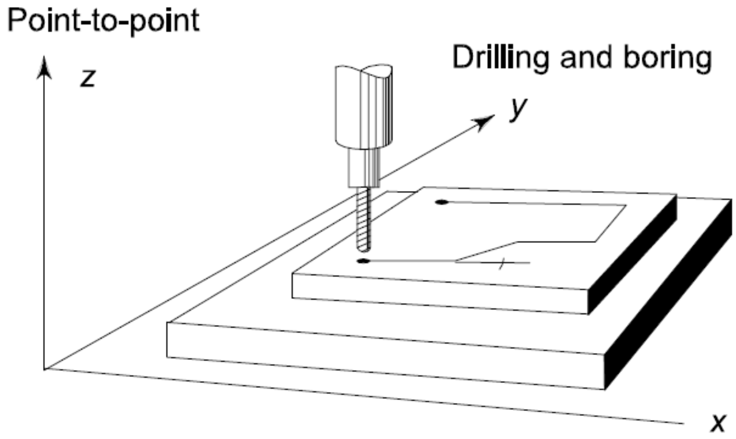


Figure 2-4:Point-to-Point motion

2.9.2 Straight Line Motion

The NC systems, in which the tool works along a straight line in the direction of a major coordinate axis, such as along the direction of feed during turning, boring or milling operation at a controlled rate, are known as Straight line control system.

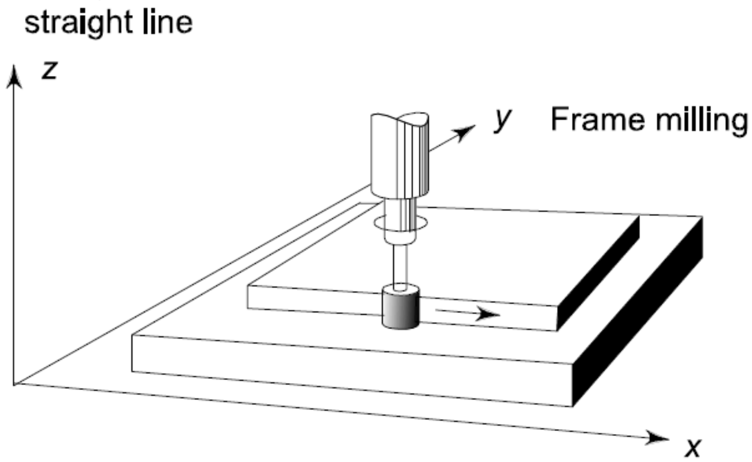


Figure 2-5:Straight-line

2.9.3 Contouring or Continuous Path Motion

Other type of machine tools involves motion of work piece with respect to the cutter while cutting operation is taking place. These machine tools include milling, routing machines etc. and are known as contouring machines and the controls required for their control are known as contouring control. Contouring machines can also be used as point-to-point machines, but it will be uneconomical to use them unless the work piece also requires having a contouring operation to be performed on it. These machines require simultaneous control of axes. In contouring machines, relative positions of the work piece and the tool should be continuously controlled. The control system must be able to accept information regarding velocities and positions of the machines slides. Feed rates should be programmed.

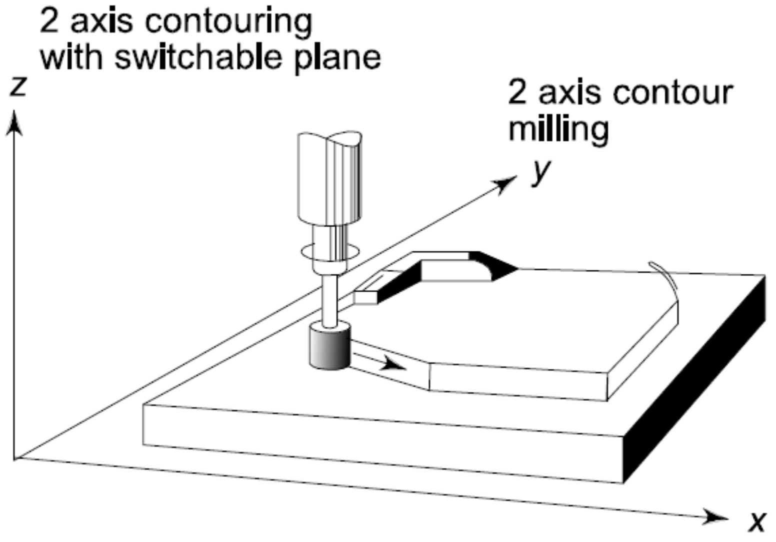


Figure 2-6:Example of Contouring or Continuous Path Motion

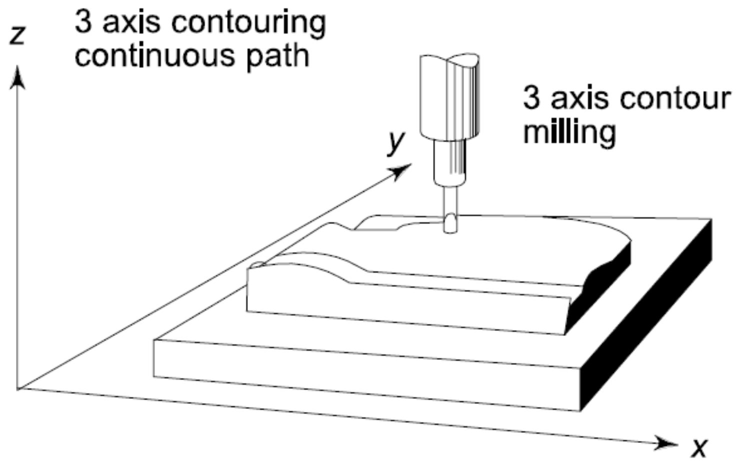


Figure 2-7: Other Example of Contouring or Continuous Path Motion Control System

2.9.4 Linear and rotational motion

There are two kinds of motion, linear and rotational. Linear movements are produced by the different axes moving along their rails. Diagonal lines, and arcs and circles, are the result of two or more axes moving at the same time in a synchronized manner. Rotational movements are the result of the part or the head rotating around an axis.

2.9.5 2D, 2.5D,3& 5 axis

The difference is that 2D tool paths cut only at a single depth, while 2.5D cuts at multiple depths. In some edge cases, the line between 2.5 and 3D gets blurred a little. Both V-carving and ramping into cuts are technically 3D machining, as they are moving all three axes at the same time. However, those are more a built-in feature to the CAM software than they are a description of the part geometry.

3-axis machines move in a Cartesian manner along x, y and z. A fourth axis often takes the form of a rotating device for the part being cut, similar to a lathe or an indexing head along the spindle that permits the controlled rotation of an aggregate tool. 5-axis machines have a much greater range of motion and can move in a manner similar to the human hand. These machines often have a deep z stroke to be able to work in a large three dimensional area. There are 6 possible axes of motion, 3 linear and 3 rotational, one of which is considered to be the cutter spinning in the spindle.

2.10 Control Software

There are several controller packages available to the user. Some are standalone software that support a wide range of hardware choices. Others are specific to work exclusively with a specific hardware controller, which would be considered a proprietary-based system and should be avoided if possible. Some are free whereas others almost require a second mortgage. As a user, your aim should be to find a controller package that is capable of interfacing and controlling hardware that is commonly available, as well as work with various peripheral devices.

2.10.1 G-Code

The G-code language is an alpha-numeric ASCII-based machine-command language that the controller interprets into discrete movements and modes. This is not the type of programming language that requires it to be compiled prior to use. However, it does need to adhere to a specific flavor or dialect that your controller can interpret and make use of.

2.10.2 Mach3 Control Software

Most CNC users have either used, do use, or have at least heard of the Mach3 Software. Without a doubt, it is the most popular controller software available. The Mach3 software runs on PC-controlled (via Microsoft Windows) operating system, can operate up to six axes simultaneously, and has considerable built-in functionality. This package supports user-defined Visual Basic macros and allows the user to enhance or completely rewrite the "front end", along with custom macros. This allows users to change and customize the look and feel of the application to suit their needs.

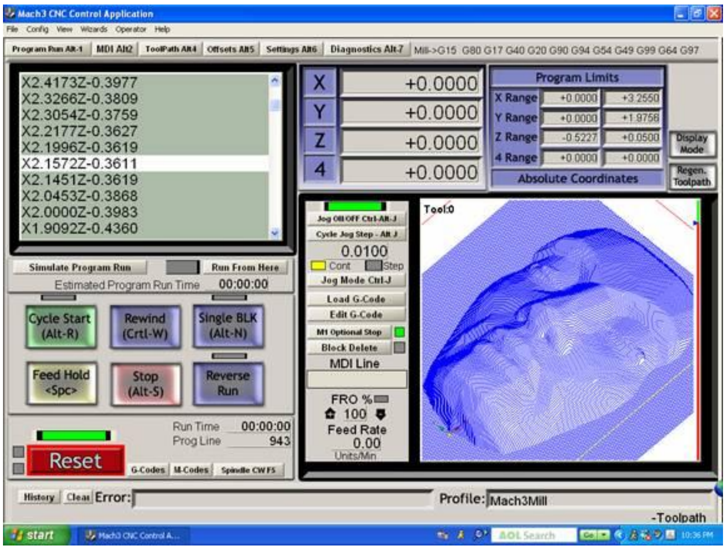


Figure 2-8: mach3 screen

2.10.3 GRBL

Grbl is G-code interpreter written for the Arduino platform. It is written in the C programming language without going through the Arduino IDE to be able to squeeze as much functionality out of the limited memory of the Arduino as possible. Grbl takes its input from a computer connected through the Arduino’s USB cable, translates the G-code into stepper motor control signals, and outputs these stepper motor control signals through dedicated output pins. The signals are then fed through stepper motor drivers to the stepper motors driving the CNC machine axes. Grbl is distributed as open source through the permissive free software MIT-license.

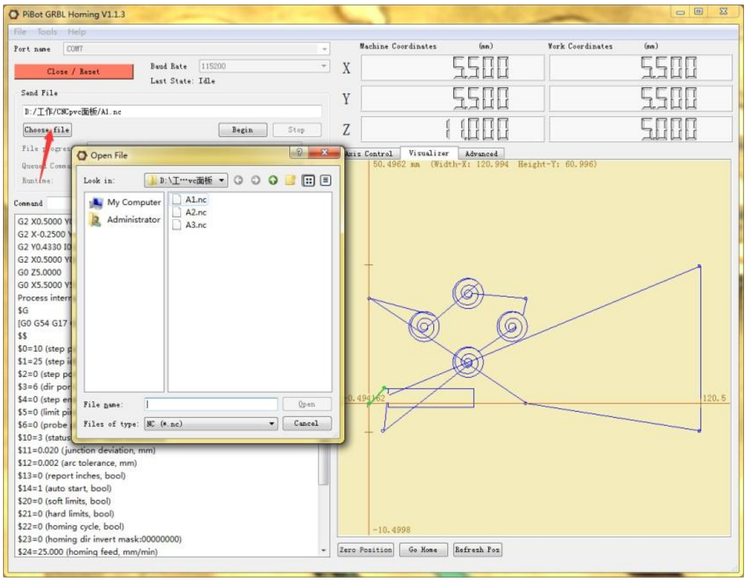


Figure 2-9:PiBot GRBL Homing software

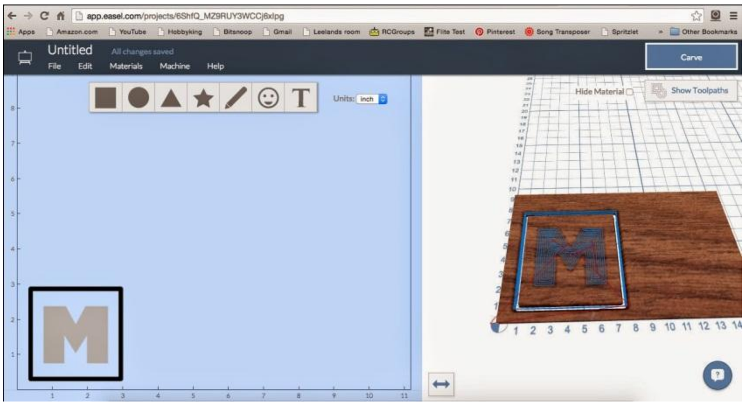


Figure 2-10:EASEL software

2.11 **Conclusion**

In this chapter, we introduced the phase which when the programmer starts from an imagination of the desired shape, passing through CAD soft, than CAM soft, than finally G-code file to be send by G-code sender soft, to be uploaded to the Arduino IDE.

Also the classification of the CNC based on the CNC motion; we also discussed the differences between the terms of 2D, 2.5D,3 & 5 axis.

Finally, comes the some famous softwares used to control the CNC machine.

Chapter 03: Designing the CNC machine

Chapter 3 : Designing the CNC machine

3.1 Introduction

This chapter briefs on the construction process of building a router table, the specialty is the wood carving. First we must mention the (DIY) projects for its important role in obtaining the schemes and plans of the CNC machine for the hobbyist and student as well around the globe.

After that, mentioning the chosen mechanical design for this CNC machine, then the electric and electronic design, along with the tool and the components used in.

Finally, the software used in uploading the G-code and monitoring the process.

3.2 Do-lt-Yourself (DIY)

Performing a simple Web search will give you many plans for DIY CNC machines. The bulk of them will typically call for wood, plastic, or aluminum for the construction materials and usually have a rather small cutting footprint. It's typically the budget that mandates what type of construction materials is used.

If you are interested in building your own table that can be used for routing, plasma, water jet, etc., then you should check out the DIY websites They, offer free plans, advice, and also give recommendations where you can obtain manufactured parts if you are not able to make them yourself. They also guide the user through all of the details that are involved in building your own hardware controller and have a fairly extensive online forum for interactive questions with other builders. Using their plans you should easily be able to scale up or down a machine that suits your needs.

3.3 Designing the 3D carving machine

Among all the types of CNC, the choice was the CNC router or the 3D carving machine because it was the one suitable for the need. And for that, a lot of researches are made in many plans and designs to obtain this one scheme.

3.3.1 Technical information and calculations

For the first axis Y, that supports all the weight of other axis, it’s been handled with care; the axis is rolling on 4 wheels.

3.3.1.1 Axis Y's wheels

These wheels are bearings covered with a material called(cast nylon),the wheels of cast nylon have many advantages like:

- Noise reduction
- Low coefficient of friction
- Floor protection
- Resistance to corrosion
- No maintenance is required
- Electrical and thermal insulation
- Vibrations are damped
- Long duration life

The bearing features are stated in the guide system title, basing on their features, the bearing are more than enough to sustain the motion and the load

3.3.1.2 Calculation of the forcesto move the Y axis

The force required to move the first axis Y should be superior of the force named F_f.

From the laws of physics:

$$F_f = F_a + F_r \text{………(1)}$$

F_f: the forces applied in case of moving wheel

F_a: is the force of acceleration of the axis.

F_r : are the resisting forces of the movement of the axis, it includes the frictions.

By the Newton's second law, we have:

$$F_a = m \times a \text{………(2)}$$

m: the mass of the hole axis, approximately 14 kg ±1

a: the acceleration of the axis, the maximal acceleration is given from the constructor, and it's 15.43 round/sec^2, this is an angular acceleration, the pitch of the lead screw is 2mm. so the linear acceleration is 15.43 ×2=30.86 mm/ s^2

We apply the formula (1),

F_a = 14×0.3086 = <u>4.284N</u>

For $F_r$the resisting forces we consider just the rolling resistance namedR_r.

By the Coulomb's law, we have

$$R_r = f_f \times \text{W/R}.........(3)$$

Tread Material	Floor Material	Coefficient of Rolling Friction (inches @ 3mph)
Forged Steel	Steel	0.019
Cast Iron	Steel	0.021
Hard Rubber	Steel	0.303
Polyurethane	Steel	0.030 - 0.057*
Cast Nylon	Steel	0.027
Phenolic	Steel	0.026

Table 3-1: Coefficient of rolling friction

From the table 3-1, we extract the rolling friction coefficient of Cast Nylon with steel, knowing that the maximum speed of the axis is 33.33 mm/s.

f_f = Coefficient of rolling friction (units must match same units as R (radius)) between the iron and the cast nylon: 0.00067 m (we neglect the coefficient of rolling friction of the bearing, because it to small compared to other coefficient

W = Load on the Wheel/ we have 4 wheels, that means the load will be divided on 4: 3.5 kg.m/s^2

R = Radius of the Wheel: 0.021 m

We apply the formula (3):

$$R_r = 4 \times (0.00067\times35/0.021)$$

$$R_r = 4.46\ N$$

So, the force F_f:

$$F_f = F_a + F_r$$

$$F_f = 4.284 + 4.46 = 8.744\ N$$

3.3.1.3 Calculation of cut force F_C

Secondly, we calculate cut force named F_C, means the necessary forces so the machine can carve wood. The formula (5) calculate the force cut of one tooth per tool

$$F_C=(K_C \times A_D)/60\ldots\ldots(4)$$

K_C= Brinell hardness of the dry hardest wood: 10 N/mm^2

A_D=Material chip section

$$A_D=(2\times f\times a_r \times a_a)/(\alpha\times D)\ldots\ldots\ldots(5)$$

f: Advance of tool, (linear speed advance of tool/rpm of tool):0.1mm/round

a_r:Width of material in case if space carved is less than the diameter of the tool, else it's the diameter of the tool, in our case it's the diameter of the tool: 4mm

a_a= Depth per pass: 2 mm

α= Bit attack angle(in wood most case, and our case α= π/2)

D= Diameter of tool: 4mm

Applying formula (5): A_D= 0.25mm

Applying formula (4) for two teeth: F_C =0.084 N

Now we calculate the total force $F_T = F_C + F_f$ = 8.828N

Now we calculate the power of total force $P_T = F_T \times S_S$

S_S= Max linear speed of Y axis: 33.33 mm/s

Then P_T=8.828×0.333= 2.94 W

Now, we calculate the power supplied by the stepper motor named P_m

$$P_m = T_m \times W_m\ldots\ldots..(6)$$

T_m =Torque of stepper motor(from the figure): 0.59N.m

W_m =Speed of stepper motor: 1000 rpm= 16.67 rps

We apply the formula (6): P_m= 9;84 W

Now, applying the safety coefficient to P_T, which is between 2 to 2.5; so the power required from the motor of the axis Y to work safely is P_r= 2.5×2.94=7.35 W

3.3.1.4 Results

Comparing $P_m$to P_r, the power of stepper motor is far enough to satisfy the needs of the machine.

Regarding that Y axis support huge load compared to the other axis, and the 3 stepper motors are identical. So finally, the choice of stepper motor is convenient, and they can support additional friction due to the imperfection of work.

3.3.2 Main structure

The base of the machine is square table made of iron square tube, with adjustable rubber feet, capable of adjusting its position, in the same time, to absorb the vibrations due to the movements of motors.

The table's dimensions are 107 by 107 cm, with 50 mm iron square tube; its thickness is 2 mm.

The machine is capable of working within surface of 57×57 cm, with a maximum piece of material 78× 95 cm.

The table, where the material sits is immovable.

3.3.3 Guide system

The guide system is the methods in which the individual axes of the machine derive their motion.

For the machine, it's a simple and effective one it's (DIY) guide system based on ball guide system.

For the Y axis, it consists of 10 bearings (ID=8, OD=22, Max load=2.111KN, Max speed=28800 rpm) covered with (cast nylon)for its properties. 2 wheels from above and one from below as shown in (Figure 3-2). And 2 wheels from inner side as shown in (Figure 3-1)

And for X axis guide system it consists of 12 bearings (ID=6,OD=19,Max load=1.474KN, Max speed=30600 rpm)mounted as shown in (Figure 3-4)

Finally for the Z axis, the guide system is the drawer guide of a good quality also based on ball guide system, as shown in(Figure 3-3)

Figure 3-2: side of the Y axis guide system

Figure 3-1:inner side of Y axis guide system

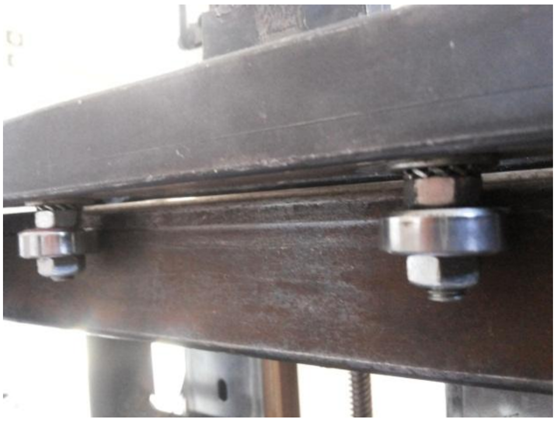


Figure 3-4:X axis guide system

Figure 3-3:Z axis guide system

3.3.4 Transmission system

The transmission systems are the methods in which the rotary power from the motor is translated into linear motion.

The task of this CNC is simple and easy kind of, thus the transmission system is the leadscrew and nut, it is exactly as shown in figure 3-6

The lead screw is related to stepper motor by flexible shaft coupling (Figure 3-7)

The flexibility of the coupling allow absorption of the vibration from the motor and the lead screw as shown in (Figure 3-5)

The lead screw is mounted to the machine by self-aligning ball bearing; the advantage of self-aligning ball bearing so lead screw can adjust its position to obtain the optimal aligning (see Figure 3-7)

Figure 3-5: Lead screw assembly with one-piece nut

Figure 3-6: example of flexible shaft coupling

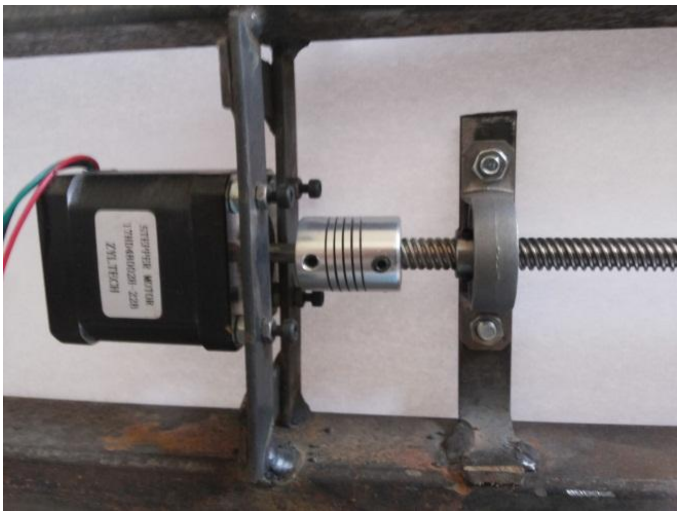


Figure 3-7: stepper motor coupled with lead screw by flexible shaft coupling

Figure 3-8:front view of the CNC machine

3.3.5 Electric and electronic hardware

In this part, all the electrics and the electronics component shall be mentioned like the motors and driver motors and the power supply and other things. And in the Figure 3-9 shows a general scheme for a typical electrical system

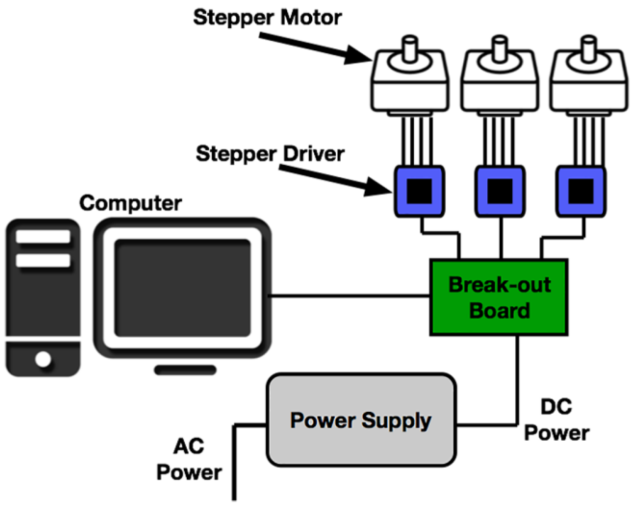


Figure 3-9: overview of a typical electrical system

3.3.5.1 Power supply

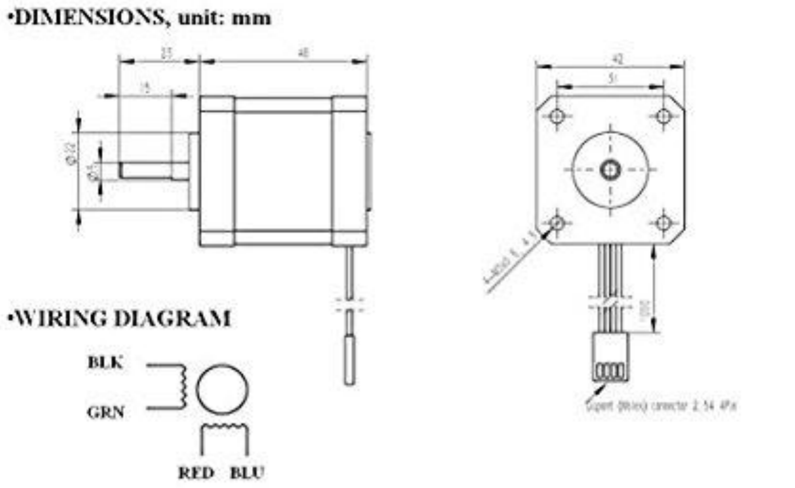
The power supply unit should satisfy the power needed for the breakout board and the stepper motor driver, a search was made and the result was that, specific power supply units are destined for the CNC machine, but expensive and for that we thought about the power supply unit of a computer, so we checked its outputs, and it fit the need.

The power supply unit delivers at maximum 12 v and 6 A.

3.3.5.2 Motor

For the machine is simple, it doesn't need closed loop system, so it's an opened loop system, that means there is no feedback to the control unit, which means the machine depends upon the ability of the drive systems to move the slide through the required exact distance. The most common method of driving the lead screw is by a stepper motor. The stepper motors are the simplest way for converting detail electrical signals into proportional movement. As there is no check on the slide position, the system accuracy depends upon the motors ability to step through the exact number of steps provided at the input.

There are many kind of stepper motors and for the machine the choice was on NEMA 17, see its feature in Figure 3-10. Its power is sufficient to move the axis as calculated before.



•SPECIFICATIONS

Number of phase	2	Phase Resistance	1.8 ohms
Step Angle	1.8°	Rated Voltage	3.06 V
Step Accuracy	5%	Inductance	3.8 mH ±20%
Holding Torque	0.59 N·m (84 oz·in)	Insulation resistance	100 MΩmin (500V)
Rated Current/	1.7 A/phase	Insulation class	Class B
Rotor inertia	82 g cm²	Weight	406 g

Figure 3-10: overview of stepper motor properties

3.3.5.3 Break-out board

As it's mentioned before, Arduino is the breakout board for the machine and in the same time as interfacing board between the driver motor and the computer.

The Arduino itself can't drive the stepper motor, so it needs other chips, the first one is the CNC shield, it connect to Arduino on top of it relating through convenient pins.

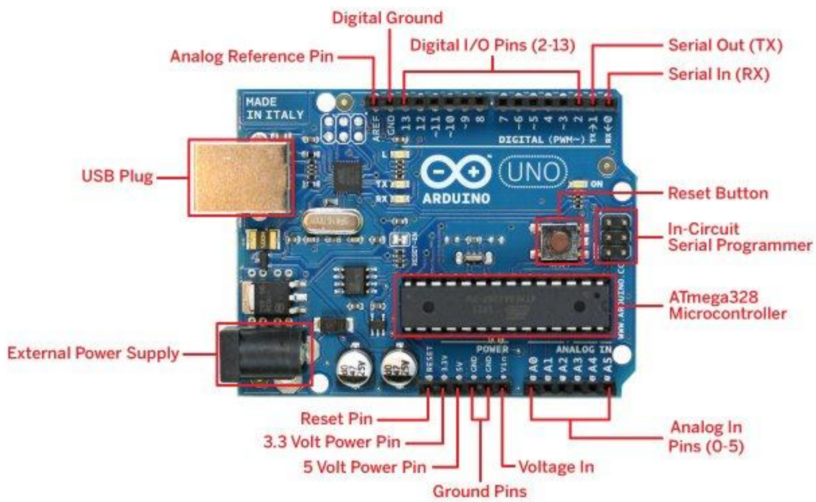


Figure 3-11:Arduino Uno board pins description

Features of CNC Shield

- GRBL 0.8c compatible. (Open source firmware that runs on an Arduino UNO that turns G-code commands into stepper signals (https://github.com/grbl/grbl)
- 4-Axis support (X, Y, Z , A-Can duplicate X,Y,Z or do a full 4th axis with custom firmware using pins D12 and D13)
- 2 x End stops for each axis (6 in total)
- Spindle, Coolant enable and direction
- Uses removable Pololu A4988 compatible stepper drivers. (A4988, DRV8825 and others)
- Jumpers to set the Micro-Stepping for the stepper drivers. (Some drivers like the DRV8825 can do up to 1/32 micro-stepping)
- Compact design.
- Stepper Motors can be connected with 4 pin Molex connectors.
- Runs on 12-36V DC. (At the moment only the Pololu DRV8825 drivers can handle up to 36V)

3.3.5.4 Driver motor

As for the driver motor, what is needed for the CNC is the A4988 stepper motor driver; it delivers micro steps signals suitable for the function of the stepper motors. The A4988 is a complete micro-stepping motor driver with built-in translator for easy operation. It is designed to operate bipolar stepper motors in full-, half-, quarter-, eighth-, and sixteenth-step modes, with an output drive capacity of up to 35 V.

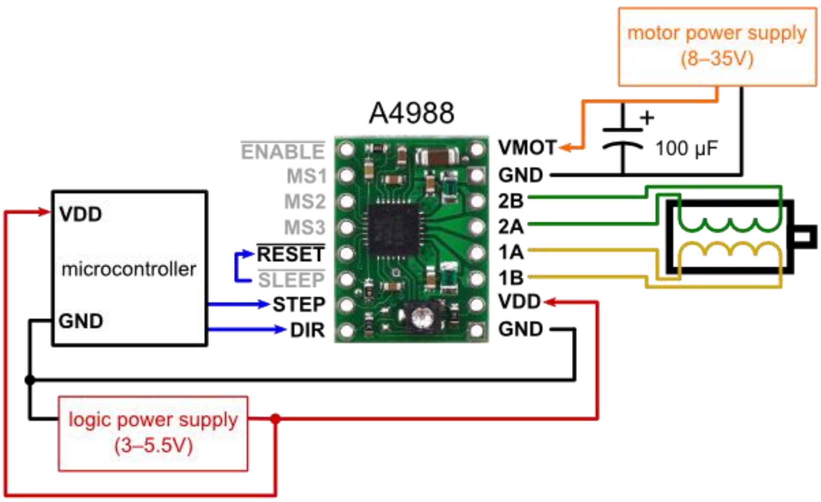


Figure 3-12: wiring the A4988 driver

3.3.5.5 End stop

The end stops are used as micro-switches, which are mounted such as to sense the physical extremes of travel for each axis and in each direction of travel. When using the switches in a capacity of limits, they are intended as safety devices to immediately stop travel of the axis prior to a crash or the gantry running off the end of the table.

There are many kinds of end stop, and for this CNC; we preferred the optical end stop for many reason, we shall mention the decisive one, there is no physical contact between the machine and the optical end stop, and that prevent the failure of the device.

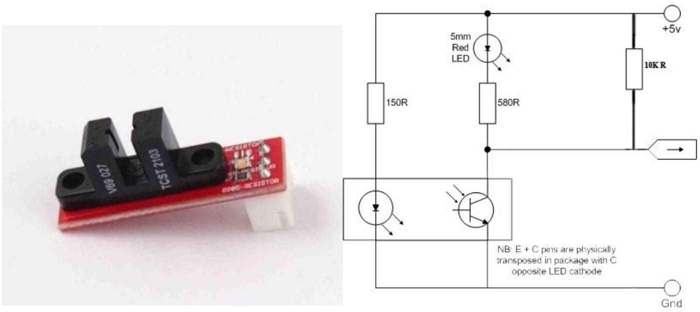


Figure 3-13: example of an optical end stop, its electronic scheme

3.4 Control software

As the breakout board is Arduino, it has its own control software, its name is Arduino.

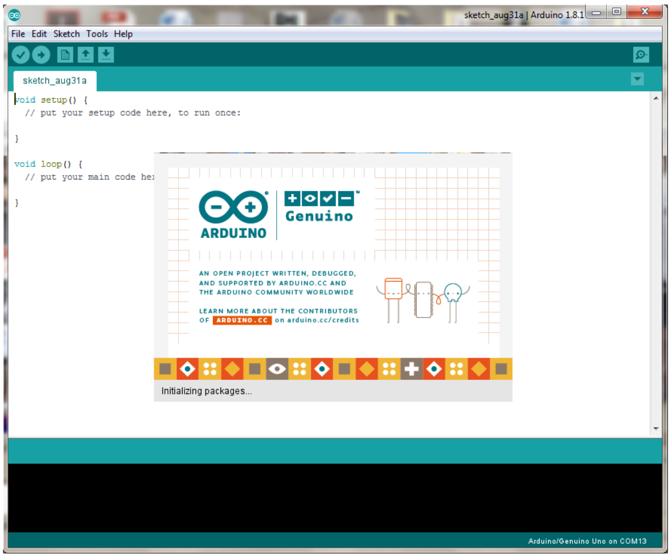


Figure 3-14: Arduino control software (screen shot)

From this window anyone can write any instructions, verified them, then upload it to Arduino through selected com port. But for controlling CNC machine, G-code interpreter written for the Arduino platform(Grbl), is executed through Arduino soft by including the Grbl library, to be able to squeeze as much functionality out of the limited memory of the Arduino as possible.

Download a copy of GRBL from: https://github.com/grbl/grbl

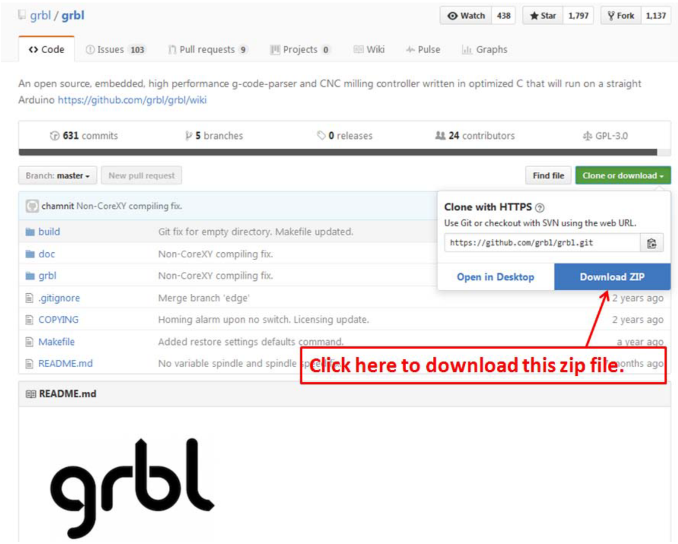


Figure 3-15: screen shot of web site(https://github.com/grbl/grbl)

After this step, there are many ways to send the desired shape to be carved. There are online soft and offline soft each one its properties; I mentioned an example from each type in the second chapter.

If you already have the G-code of the desired shape, then what you need is just G-code sender soft. But if you have the shape's design in one of the CAD soft, then what you need is CAM soft to transfer the design into G-code.

The third case is if you have nothing but an imagination of the shape in your mind; then you need the help of one of the online soft like EASEL, there you have samples and shapes that you can modify them in a limited manner until you have your desired shape, connect your machine to EASEL, configure some settings then start machining.

When you select one of the softwares, there is an important phase before machining; it's the configuring of the dimension of the table then the size of the bit to be used in carving, the speed rate of the tool, and other important settings.

3.4.1 Implementation phase

The implementation phase consists of the steps made to obtain a final work piece.

3.4.1.1 Grbl configuration

Download Grbl from the website mentioned before, and upload it into Arduino IDE, then it comes an important step, it’s configuring the Grbl setting relatively to stepper motor features through universal G-code sender soft; By following these steps:

- Universal G-code sender is free soft, so it can be downloaded by tapping its name in Google search engine, then downloading it from any proposition of google; install the software then lunch it. The soft based on Java system, so it needs Java installed in your computer.
- When it’s lunched, a window appears as shown in figure 3-16, in the selected area, the port number must be selected to connect to Arduino, also the Baud number given from github website, select the firmware zone too, finally clicking on button “open” if it’s successfully connected a message will appear in console as shown in figure 3-17.

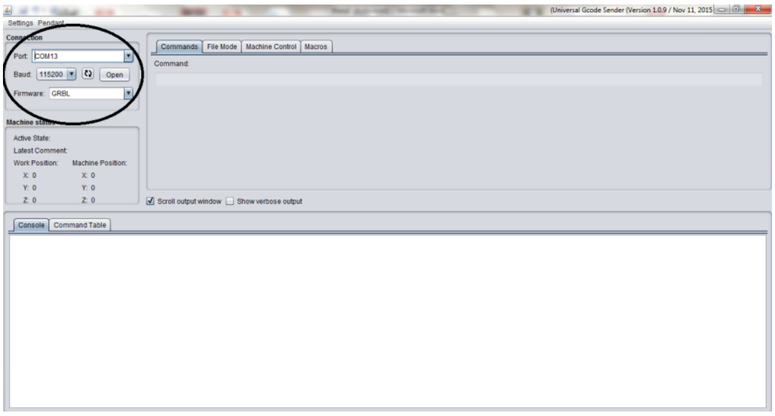


Figure 3-16: universal G-code sender main window

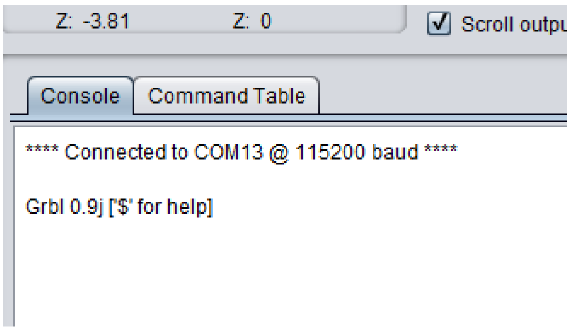


Figure 3-17: console message (universal G-code sender)

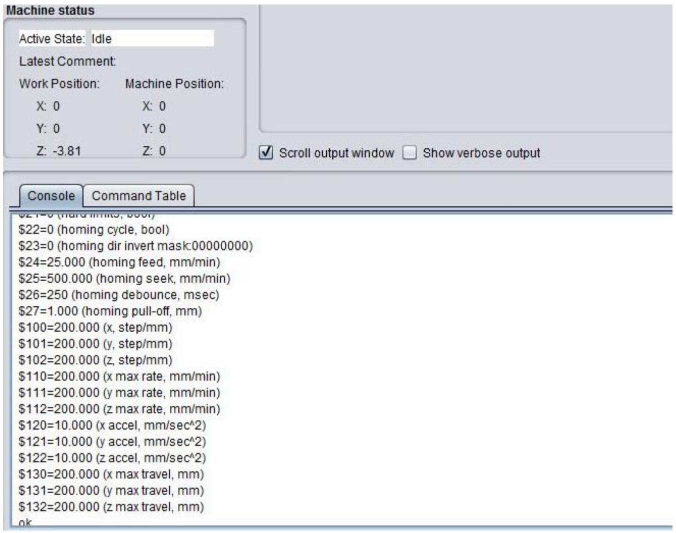


Figure 3-18: Grbl setting (universal G-code sender)

- In the “commands” tab in soft main window, write $$, then a setting list appears as shown in figure 3-18. The list contains various setting, the configuration of this setting depends the features of stepper motor and other properties.

3.4.2 First attempt

With the aid of a dearest friend we managed to design a similar logo to our university’ logo using a CAD soft which is SOLIDWORKS. Some pictures of final design are shown in figure 3-19

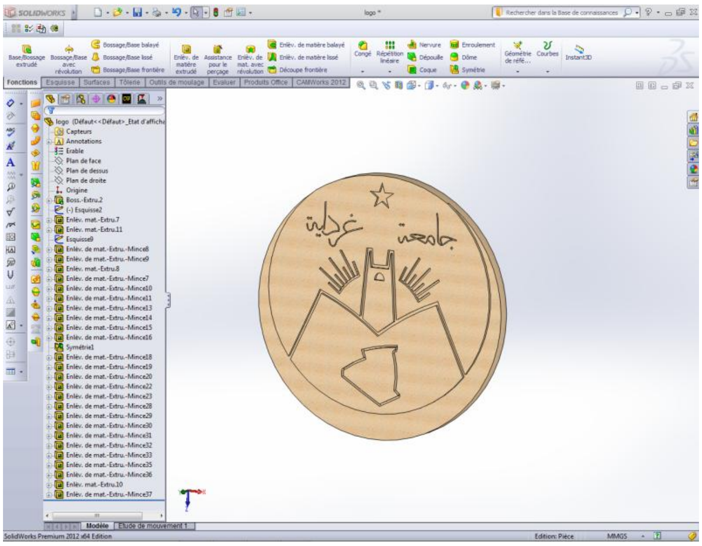
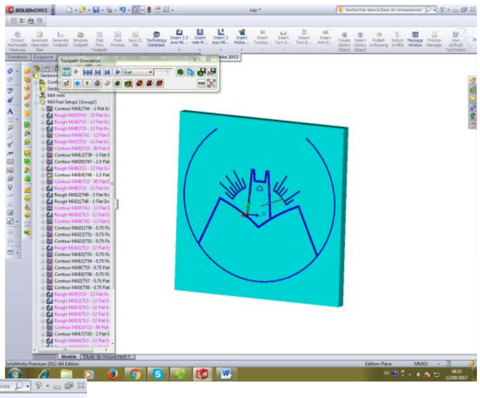


Figure 3-19: logo designed by SOLIDWORKS

Figure 3-20: tool path simulation, (in process)



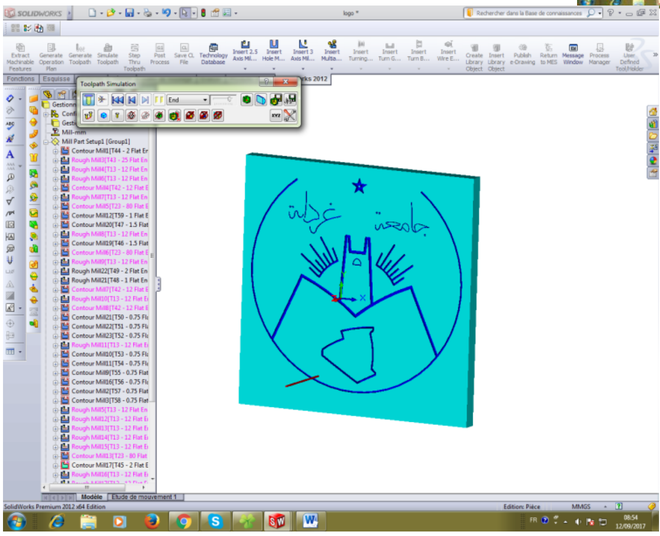


Figure 3-21: tool path simulation (CAMWORKS soft)

Using CAM software, which is CAMWORKS, we managed to simulate tool path, bit size, and other parameters, but failed to convert it into G-code file, the reason is that, we don't possess the license of the soft so machining the part was something far to achieve.

We tried other means, like converting the file using free soft, but the resulted file was full of syntax errors, so the uploading soft rejected the G-code file.

3.4.3 Alternative solution (using EASEL)

The use of EASEL website, or others websites seems to be the only choice remaining for the time being, these following steps mention how it's done

- Opening the easel web site, http://easel.inventables.com/, it will ask you to create an account, so create one, then sign in? (see figure:3-22)

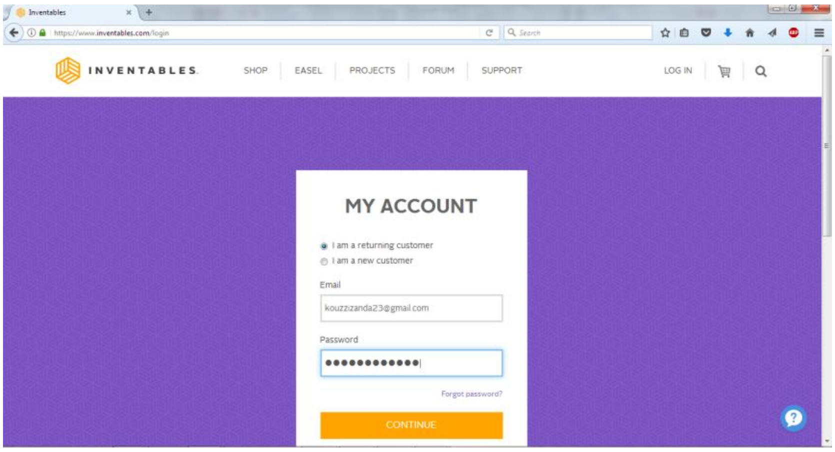


Figure 3-22: screenshot for (sign in) window (EASEL)

- The site opens, then it appears as shown in figure3-23

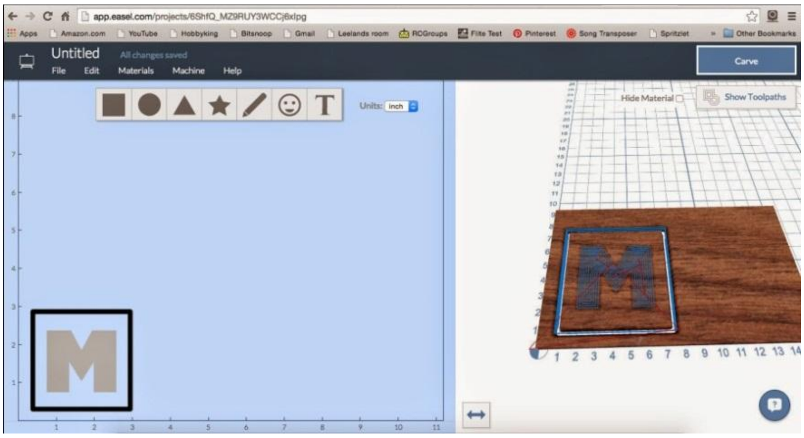


Figure 3-23: screenshot of main front (EASEL)

- EASEL web site contains libraries of icons, shapes and also limited list of fonts in English language. Also you can upload G-code and SVG files. Limited details of possible shape can also be extracted from picture file.
- The choice of shape is a gazelle, as shown in figure3-24; to the right of the same figure, the cut setting to be configured, like the depth per pass, this configuration depends on the used material and the size of the bit; also the material's dimensions must be set in the same window.

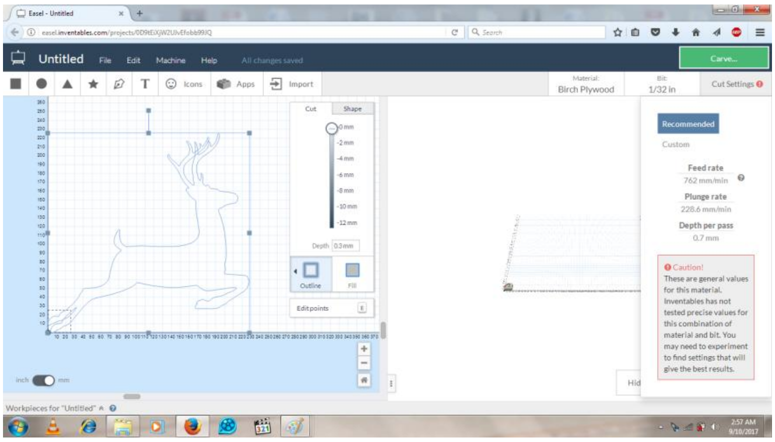


Figure 3-24: the chosen shape, cut setting (EASEL)

- When the button (Carve) appears green as shown in (figure 3-24), it means the machine is connected to EASEL, else by clicking the Carve button to enter manually the COM number, which USB port the machine is connected to computer.

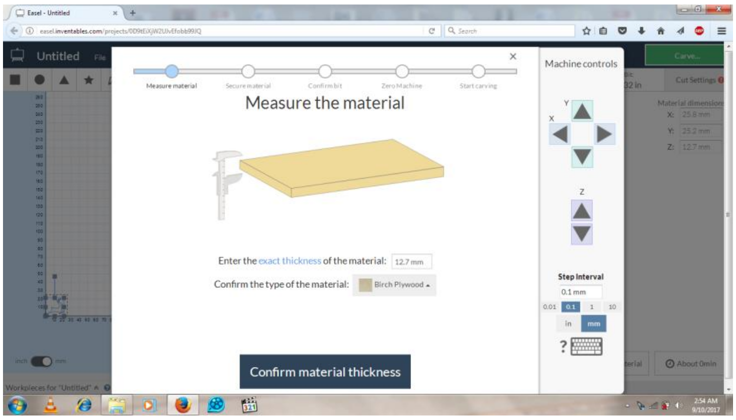


Figure 3-25: confirm material thickness window (EASEL)

- When the machine is connected and the button (Carve) is clicked, a window appears to confirm the material's thickness, with the ability to move the three axis, as shown in (figure 3-25).

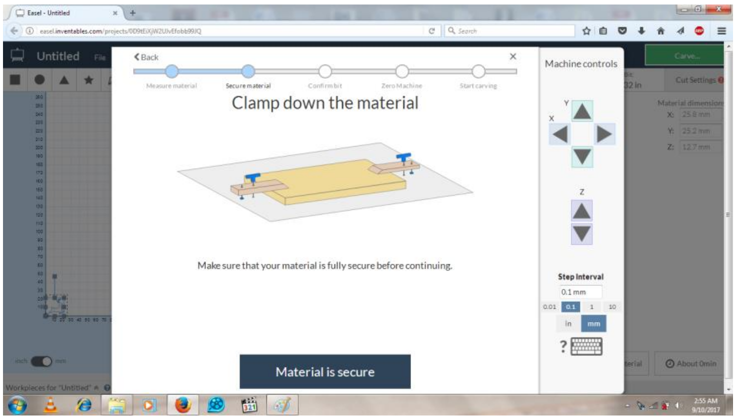


Figure 3-26: confirm of the material is held (EASEL)

A second window appears to check if the material is held, (see figure 3-26) after confirmation another window appears to select the bit size, (see figure 3-27)

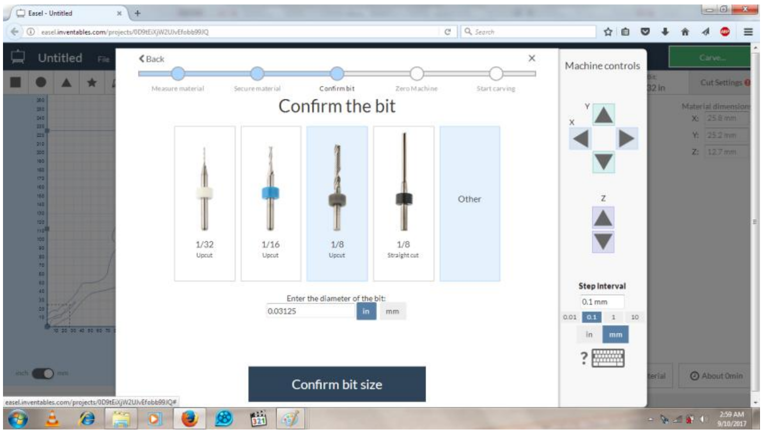


Figure 3-27: selection of the bit size (EASEL)

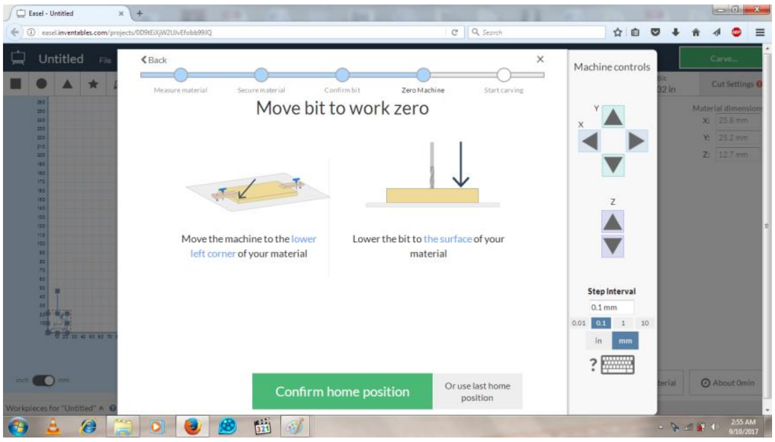


Figure 3-28: setting the home position (EASEL)

- Another window appears to confirm position zero, and also the position of bit, as shown in figure 3-28.

- The last window appears, first case if the spindle is controlled by EASEL through Arduino, the window appears as shown in figure 3-30 , else EASEL asks you to turn on the spindle manually as shown in figure 3-29

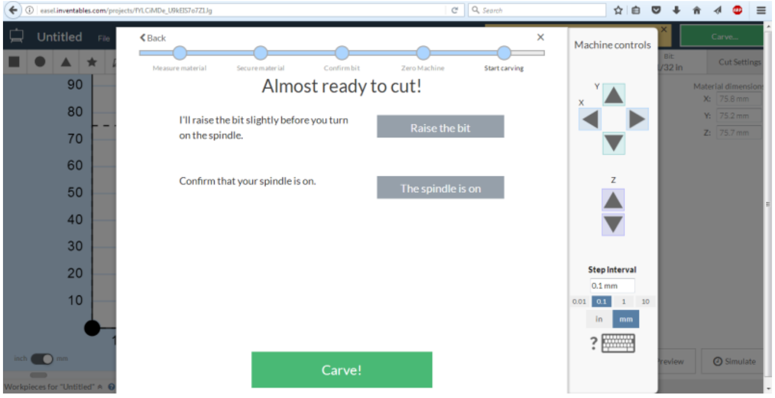


Figure 3-29: spindle is controlled manually

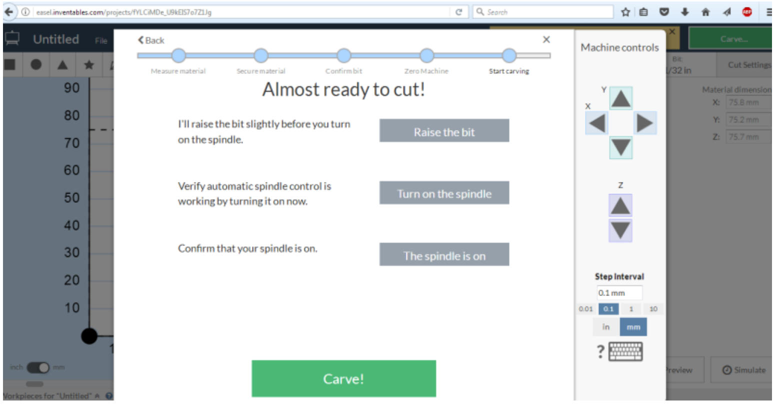


Figure 3-30: spindle is controlled by EASEL

Finally by clicking Carve! Button the operation will start, displaying operation duration, also with pause and abort buttons.

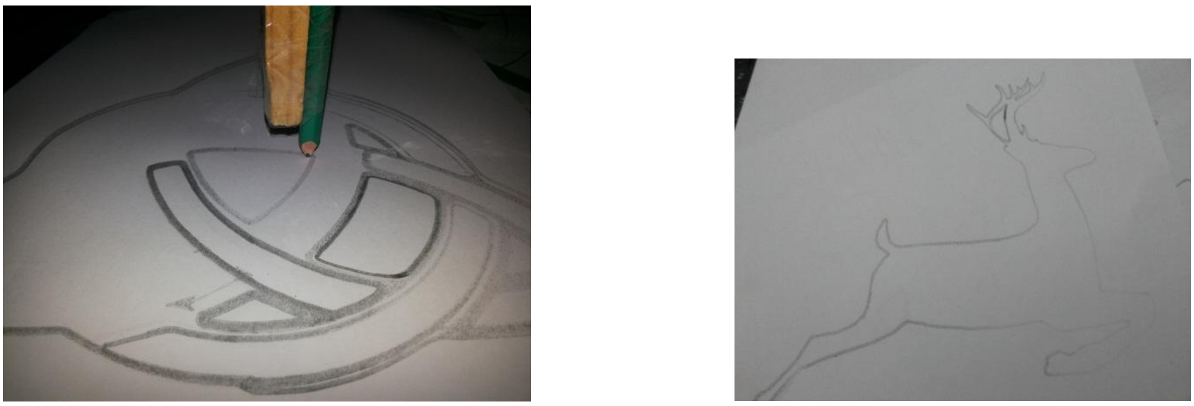


Figure 3-31: examples of drawings using CNC machine

In the implementation phase we executed some 2D and 3D shapes.

For some simple testing and little experiments, a pencil is mounted to the CNC machine to act like a tool, using these steps, so finally getting some drafting and some drawing. (see Figure2-31)

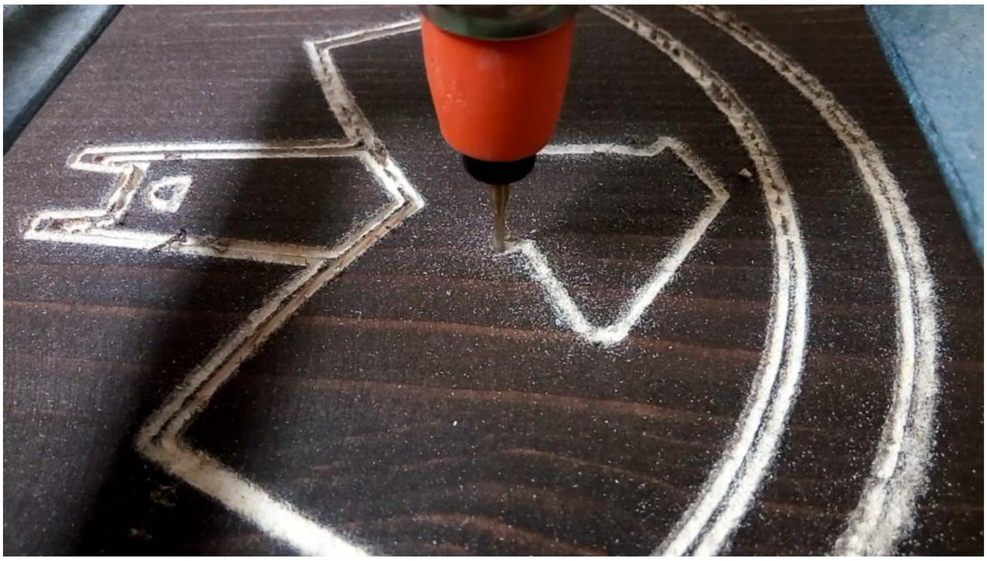


Figure 3-28:Carving in process (logo of Ghardaia University)

And for some real carving, the logo of Ghardaia University that is designed before was loaded into Arduino board of the machine and carved, a piece of wood is painted with a dark color, so when the tool carves, the shape will very clear.

Figure 3-29: The final piece (Ghardaia University logo)

3.5 Financial calculations

Under this title, all the expanses of the project are stated, from the main structure materials to electronics and software.

First, we begin with hardware and tools purchased from outside the country using EURO currency.(see table 3-2)

Product name	**Unit price**	**amount**	**total**
Lead screw 60 cm	9.59€	2	19.18 €
Lead screw 40 cm	8.59€	1	17.18 €
Shaft coupling	1.5€	3	4.5 €
Self-aligning bearing	1.3€	6	4.8 €
Nema 17 stepper motor	16.59€	3	49.77 €
ArduinoUno+cnc shield+ 3 driver	15€	1	15 €
Optical end stop	1.12€	6	6.22 €
Spindle head+Power Supply Speed Governor	94.59€	1	94.59 €
Set of end mill	12.99€	1	12.99 €
TOTAL	224.23€		

Table 3-2: list of purchased products from Europe

Secondly, the tools purchased from Algeria are shown in table 3-3

Product name	**Unit price**	**amount**	**total**
50mm iron square tube	1500 DA	1	1500 DA
35mm iron square tube	1000 DA	1	1000 DA
Ball bearing (ID=8, OD=22)	250 DA	10	2500 DA
Ball bearing (ID=6, OD=19)	200 DA	12	2400 DA
Pair of drawer guide	450 DA	1	450 DA
Adjustable feet	100 DA	4	400 DA
Screws and nuts	500 DA	1	500 DA
25mm iron square tube	900 DA	1	900 DA
Stepper motor driver	650 DA	2	1300 DA
Power supply unit	1100 DA	1	1100 DA
TOTAL	20600 DA		

Table 3-3:list of purchased products from Algeria

Using currency transfer, the total is: 51992 DA, it means the materials of the machine costs 51992 Algerian Dinars.

3.6 Evaluation phase

The project is finished, but some parts remain undone, for example, the optical end stop switch remains undone because it needs separated section of programming, the process is known for us, just the lack of detailed information and time.

We managed under the pressure to carve in the wood.

The machine faces vibrations, noise and friction; we try to minimize them, by adjusting the step resolution, the current level and also speed. Noise remains, and the vibration decreased to acceptable level.

The power of the stepper motor can overcome the friction because of its huge power.

The backlash is almost zero.

3.7 Improvements of CNC machine

Due to power of stepper motors, the machine can carve on both plastic and aluminum.

For the improvements of this CNC machine, we can state this:

- Adding and Programming the optical end stop switch.
- Reducing the noise by testing new setting for the motor drive, testing also other type of driver motor, taking also in consideration improving and perfecting the guide systems.
- Replacing the simple nut by anti-backlash nut to reduce backlash.
- To manage controlling the spindle by Arduino,
- Switching from open loop system to closed loop system by using the optical end stop switch as decoder, so the carve will be more accurate and precise specially for plastic and aluminum carving.

3.8 Conclusion

In this section we managed to describe the 3D carving machine in a simple manner, beginning from the main structure, the base, the adjustable feet and others. Then we moved to the guide and the transmission systems.

An important step in designing CNC machine is power and forces calculation, which it is introduced in this chapter as well, of course as accurate as possible.

Then we passed to the electrics and the electronics, passing by Arduino and its accessories.

Also, speaking about the required steps to obtain from a desired shape or simple draft, G-code files, with all the software associated or used with.

Then, we passed to the implementation phase which, it consist of all the steps required to carve using EASEL website.

The evaluation phase, it’s an important step, it evaluate the level of achievement of CNC design.

Finally, the possible and the required improvements for the CNC are mentioned, in order to be more efficient and more reliable in other powerful task.

Conclusion

The project started with a description of the CNC machine in a general way with its history, and some classifications and types. Then, the part programming, it mention the fundamental steps toward final file to be uploaded into Arduino, the file describes the desired shape. And for the final phase we described the built machine, starting from the primer design to physical structure passing by the programming step, finishing with the tests and trials.

The project faced many difficulties, starting with the construction of the main structure; it took 50% of time and effort. Then comes the programming part with 30% of the time and effort, the remaining 20% goes for writing.

The project has achieved 90% of the plans decided for it, some plans remains undone, as it’s mentioned before. The project also suffers some noise and vibrations, these all must be taken in mind to be rectified.

As for the improvement, starting with mounting the messing devices, transferring to closed loop system, and others as mentioned before.

This thesis is just briefing of the CNC world, many chapters might be included, stating many thing as the bits and the end mill features and uses, guarding and safety devices and security measures, also it lacks of mentioning the 3D printing field, along with long list.

We hope that this work opens an appetite for the students and the teachers alike, to uncover and explore this field, in the same time a push toward the evolve of the university.

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